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AT HARVARD COLLEGE.
Vol. XXXIII.

THE ISLANDS AND CORAL REEFS OF FIJI.

By Alexander Agassiz.

With One Hundred and Twenty Plates.

CAMBRIDGE, MASS., U. S. A.:
PRINTED FOR THE MUSEUM.
May, 1899.

BULLETIN

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AT

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The Fiji Islands and Coral Reefs. By ALEXANDER AGASSIZ.

INTRODUCTION.

On our arrival in Suva the first day of November, 1897, we found the "Yaralla," a twin screw steamer of about five hundred tons, chartered from the Australasian United Steam Navigation Company, awaiting us. The boat proved admirably suited for our purpose, the managing agent of the company at Brisbane, Mr. Elliot Bland, and Captain Downs, of Sydney, having spared no pains in fitting her out.

Previous to our departure I shipped to Australia our outfit for dredging, sounding, and deep-sea towing, as well as all the materials necessary for preserving our collections. This equipment we found safely stored in the "Yaralla." Dr. W. McM. Woodworth and Dr. A. G. Mayer accompanied me as assistants. Dr. Woodworth and my son Maximilian have taken a large number of photographs illustrating the physiognomy of the islands and reefs. Dr. Woodworth devoted his time in part to the care of the Worms, and Dr. Mayer to the Acalephs of Fiji.

I have to thank the State Department at Washington for their kind offices in obtaining for me letters from the British Foreign Office to the Government of Fiji. Sir George O'Brien, the High Commissioner of the Western Pacific, gave us all possible facilities for visiting the different islands of the group. I am also indebted to the Hon. J. Stewart, Colonial Secretary, and to the Hon. W. L. Allardyce, Assistant Native Commissioner, for assistance and advice. To Dr. Corney and the Hon. John Berry I owe information of value regarding the existence of elevated reefs at points I have not examined. To Captain Calder, the agent of the Australasian United Steam Navigation Company at Fiji, I am greatly indebted for his exertions on our behalf. Finally, Captain R. Cocks, our pilot, and Captain Thomson, as well as the officers and crew of the "Yaralla," were indefatigable in promoting our interests. I have also to thank specially Sir William C. Van Horne and Mr. T. G. Shaughnessy, the President and Vice President of the Canadian Pacific Railway, for placing at our disposal a private car from

Montreal to Vancouver, and for despatching to Fiji a number of cases which could not be shipped via Australia. I am also under great obligations to Admiral Sir W. J. L. Wharton, R. N., and to Captain W. U. Moore, R. N., for their unceasing interest and advice while planning my trip to Fiji.

Thanks to the admirable charts of Fiji, which owe their origin to the surveys of the United States Exploring Expedition under Wilkes, and their elaboration in great detail by the subsequent British surveys of Captain Denham and Lieutenants Moore and Richards, it was possible to cover a great deal of ground by picking out from the charts the interesting and critical points for examination, and thus to make a very rapid yet fairly accurate survey of the coral reefs. The accuracy of the Admiralty Charts enabled us to enter safely into the lagoons, and to select our anchorages with confidence. The reproduction here of the Fiji charts, together with photographs of the most characteristic views, will better serve to give a faithful picture of the islands and reefs of Fiji than lengthy descriptions, and I hope in the discussion of the general questions to be able to illustrate my arguments either by references to the charts or to the photographs of a group of islands of which Dana says, "The facts from the Feejee Archipelago illustrate the subject well."[1] The larger scale charts of the Admiralty, such as those of Kandavu (A. C. 167), of the south and east coasts of Viti Levu (A. C. 167, 845, 905), of Vatu i ra Channel (A. C. 379), of Makongai and Wakaya (A. C. 1250), of Suva (A. C. 1757), of Levuka Harbor (A. C. 1244), of Ovalau (A. C. 1249), of such islands as Nairai (A. C. 741), of Moala (A. C. 1252), of Ngau (A. C. 1251), and of Totoya (A. C. 1248), contain an inexhaustible fund of information regarding coral reefs, and would serve as an invaluable basis for a minute zoölogical and geological survey of any island group such as I attempted for the Tortugas.[2]

[1] Dana, Corals and Coral Islands, p. 262.
[2] Mem. Am. Acad., Vol. XI. p. 107 (1883).

CAMBRIDGE, September 1, 1898.

NOTE. — Owing to my absence from Cambridge and to the delay in preparing the Plates for this volume its publication has been delayed until May, 1899.

SOME POINTS IN THE LITERATURE ON CORAL REEFS.

It will prevent considerable confusion if, before proceeding with the account of our expedition to Fiji, I should devote a few pages to the examination of some of the literature on coral reefs, in the light of the observations we made while at Fiji.

On looking over the literature on coral reefs, one cannot fail to be struck with the amount of irrelevant matter which has been passed down from writer to writer. Statements made on hearsay have gradually become facts. The observations of inexperienced persons receive general recognition. Special cases are discussed without reference to their limited or exceptional application. The whole question is often threshed out *de novo*, so that it is difficult to separate the new from the old. And, finally, information gathered from charts is substituted for observation in dealing with questions which the latter alone can settle. Every new investigator naturally adds important information from the field he surveys, and each has in his way described the numerous and varying conditions affecting the growth and existence of coral reefs in the tropical waters of the Atlantic and the Pacific. Recent explorations have only increased the number of questions to be solved regarding coral reefs; and until the whole field has been examined in the light of these questions, it is hopeless to attempt a general revision of the theories regarding the formation of coral reefs. A revision based upon a partial examination, though it be more extensive than that of our predecessors, is usually brushed aside with the statement that even if the exception described is true, the old theory may yet be true in some other atoll region. Of course, such criticism can never end, and we may go on searching forever for this imaginary atoll, or until the last remaining atoll has been hunted down.

In many quarters it has become a question of creed to uphold the Darwinian theory of subsidence as essential to the formation of atolls and of barrier reefs. Facts and arguments supporting other explanations are ignored or explained away in the most extraordinary manner. Regions which are cited by Darwin and Dana as typical become exceptions when shown to be no longer characteristic regions of subsidence. Typical barrier reefs become patch reefs, atolls are dubbed pseudo atolls; so that the regions where true barrier reefs or typical atolls, which owe their origin to subsidence, can be examined, are little by little becoming very restricted. In fact, if we are to judge of the regions not yet examined, and which have not been examined by Darwin and Dana, there remain as extensive regions of possible subsidence only such islands as the Marshall and Carolines, some of the atolls of the Gilbert and Ellice groups, and of the Paumotus. Yet, judging by analogy of the adjoining districts of Fiji and Tonga, and of the descriptions given by Dana of the Paumotus, and by what we may gather from the charts in the light of our own exploration, it would not be launching a very doubtful proposition to assert that even in these island groups we shall find that the explanations we have given of the formation of atolls and of barrier reefs applies equally well to them. This still leaves the field open for observations in some of the coral regions of the Indian Ocean, and of the East Indian Archipelago. But in the districts which have been described as typical by both Darwin and Dana, recent observations have shown that other and more natural explanations than the theory of subsidence are sufficient to account for the formation of atolls and of barrier reefs.

As is well known, Darwin's experience among coral reefs was limited to a part of Tahiti, to the west side of Mauritius, and to the Keeling Atoll. Though he passed through the Paumotus without examining any of the islands; [1] according to the narrative of the "Beagle," Darwin saw in the distance Honden Island, passed by Taiaro along the shore of Kauehi and sailed between Elizabeth Island and Fakarava (Wittgenstein) to Otaheite. Captain Fitzroy also sailed through the Navigator, Friendly, and Fiji Islands without anchoring anywhere. Dana [2] worked among the reefs at Tahiti, Samoa, aud the Feejees, though he did not visit the Eastern Archipelago, limiting his observations to the larger islands, Viti and Vanua Levu and Ovalau. He "twice visited the Hawaian Islands, landed and gathered facts from fifteen coral islands, some of them in the Paumotu Archipelago; [3] one, Tongatabu, in the

[1] Narrative of the Surveying Voyages of his Majesty's Ships Adventure and Beagle (1826–1836), Vol. III. p. 539. London, 1839.

[2] In "Nature" (September 17, 1874, p. 408), Dana reviews a new edition of Darwin's Coral Reefs suggesting that he had not given sufficient weight to the effects of temperature in limiting the distribution of coral reefs, and differing widely from Darwin as to the limits of the area of elevation and of subsidence in the Pacific. But in spite of minor differences he speaks of the "array of facts of his own (Darwin's) observations, which illustrate the growth of coral formation"; and subsequently, in 1885, when reviewing the whole subject again, Dana says in the American Journal of Science, Vol. XXX., August–September, 1885, p. 90: "The evidence which had satisfied him (Darwin) was satisfactory to me when I first learned of his views in Australia (in 1839), . . . and more decidedly later when I had been among the Friendly, Feejee, and other Pacific Islands."

[3] Honden, Dean, Aratica, Ahii, Raraka, Manhii, Kawehe, Metia, Clermont Tonnerre, and others examined by other members of the Exploring Expedition.

Friendly group; two, Taputeaua and Apia, in the Gilbert group, and five others near the equator, east of the Gilbert group: Swain's, Fakaofu, Oatafu, Hull and Enderbury Island, as well as the reef region of the Sooloo Sea and of the Straits of Malacca."

In my account of the coral reefs of the Sandwich Islands,[1] I have given a short *résumé* of the results of the principal investigations on coral reefs since the days of Darwin and Dana down to 1889. What has been done since that time will be found referred to in Bonney's edition of Darwin's Coral Reefs,[2] in Kent's "Great Barrier Reef," in Langenbeck's sketches[3] of recent work on the subject, as well as in the reports of the explorations I have carried on in the Bahamas and Cuba,[4] the West Indies,[5] Florida,[6] and the Bermudas[7] in the Atlantic, and of the expeditions I have made to the Galapagos,[8] the Great Barrier Reef of Australia,[9] and Fiji.[10]

[1] Bull. Mus. Comp. Zoöl., Vol. XVII. p. 121 (1889).

[2] Professor Bonney (Coral Reefs, Darwin, 1889, 3d ed., Appendix II. p. 290), has evidently confounded the views of Professor L. Agassiz on the extent of the formation of the southern extremity of Florida by coral reefs, dating back to 1854, with those which I have published in 1877, in 1880, in 1888, and again in 1896. Neither Dall nor Heilprin has examined the Florida reefs; their studies have been devoted to other parts of the peninsula, and did not extend south of the northern limit of the Everglades. Their criticisms in both cases apply to the views of Professor L. Agassiz, as my observations were limited to the reef region, and did not encroach on the area examined by Dall or Heilprin. But I have plainly shown by the borings at Key West that the recent coral formation is of moderate thickness, not more than about fifty feet, and that it is underlaid by a substratum of tertiary limestones, occasionally coralliferous, of a thickness of nearly two thousand feet. The area probably covered by the coral reef of Florida at the time of its greatest expansion is approximately shown on Plate XVII., Bull. Mus. Comp. Zoöl., Vol. XXVIII. No. 2, 1896. I never made the statement quoted by Bonney that the recent coral reefs extended over any part of Florida north of the Everglades. On the contrary, I said in the conclusion of my memoir on the Tortugas and Florida Reefs (Mem. Am. Acad., Vol. XI. p. 116, 1883), "All this evidence tends to show that the coral reefs had little, if anything, to do with the building up of the peninsula of Florida, north of Cape Florida."

[3] R. Langenbeck, Die neueren Forschungen über die Korallenriffe, Hettner, Geog. Zeits., Bd. III., 1897, pp. 514, 566, 634.

[4] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, 1894.

[5] Three Cruises of the Blake, 1888, Vol. I. p. 66.

[6] Bull. Mus. Comp. Zoöl., Vol. XXVIII. No. 2, 1896.

[7] Ibid., Vol. XXVI. No. 2, 1895.

[8] Ibid., Vol. XXIII. No. 1, 1892.

[9] Ibid., Vol. XXVIII. No. 4, 1898.

[10] Am. Journ. of Science, February, 1898, Vol. V. p. 113.

An excellent account of the Samoan Reefs has been published by Dr. Krämer,[1] supplementing the earlier short notice of Dr. Graeff[2] on the reefs of the group; also interesting notes by Admiral Wharton,[3] on Submarine Banks of the Pacific. A careful account of the geology of the Friendly Islands by Lister,[4] published in 1891, seems to have escaped the attention of writers on coral reefs. A few notes on the reefs of some of the islands of the Bismarck Archipelago have been published by Dr. Dahl,[5] but the evidence he gives does not seem to me to warrant his conclusions. The great thickness of elevated reef he found (570 m.) may (as is the case elsewhere in the Pacific) not belong to the present epoch, as he takes it for granted, and no one supposes that elevation has necessarily always taken place uniformly either in time or space over any great stretch of territory.

The articles by Heilprin[6] and by Ortman[7] on what they call "Patch Reefs," do not seem to me to have any special bearing on the general theory of coral reefs. The existence of such "patches" has long been known and referred to by Darwin, and by many writers on coral reefs, as reef patches. These patches occur in localities where fringing reefs for local causes would not flourish except at a little distance from shore and play a very subordinate part in the physiognomy of the coast. I am at a loss to understand the statements of Ortman regarding the reefs of Kaneohe Bay on the north shore of Oahu. The accurate observations of Hartt[8] and of Rathbun on the moderate thickness of coral reefs off the coast of Brazil seem to have escaped Heilprin and Ortman, as well as other writers on coral reefs. Rathbun[9] has described the reefs along the Brazilian shore, and finds them all as "having very little height, but from the surface looking like massive structures." Hartt[10] and Rathbun have described the formation of extensive coral patches and the mode of

1 Ueber den Bau d. Korallenriffe, Kiel, 1897.

2 Samoa, Journal d. Museum Godeffroy, Vol. I.

3 Foundations of Coral Atolls, Nature, February 25, 1897, p. 390.

4 On the Geology of the Tonga Islands, Quart. Jour. Geol. Soc. London, No. 188, 1891, p. 890.

5 Zool. Jahrbücher, Bd. XI. p. 141.

6 Proc. Acad. N. S. Phila., 1890, p. 318.

7 Zool. Jahrb., Bd. VI. p. 682.

8 Hartt, in Chapter IV. p. 174, of the Geol. and Phys. Geog. of Brazil, 1870, describes the islands and coral reefs of the Abrolhos and the Recife de Lixo, where exist the "chapeirões," as rising straight up from the bottom from a depth of forty to fifty feet.

9 American Naturalist, Vol. XIII., June and September, 1879, Nos. 6 and 9.

10 Geology and Physical Geography of Brazil, Boston, 1870.

building up columnar masses which may eventually reach the surface forming mushroom- or even bell-shaped structures, of which enlarging rims may meet, "resulting in the formation of a connected reef surface supported by many upright pillars underneath from forty to fifty feet high," the so called "chapeirões" of the Portuguese. These patches frequently occur near the shore along the margin of a fringing reef, but are best developed in the deeper water of the Abrolhos regions and between these and the city of Bahia, growing upon the submerged rocky ledge. The number of reef building corals in Brazil is quite small, and Nullipores seem according to Rathbun to play a very important part in the building up of the limestone reefs.

Professor Bonney[1] summarizes the position of the theory of coral reefs as now left (1889) in the following terms: "That this theory may have been expressed in terms a little too comprehensive, that there may be a larger number of exceptional cases than was at first supposed, is quite possible. . . . It may very possibly be found that, as remarked by Mr. Bourne, the history of coral reefs is more varied and complicated than was at first supposed, but it seems to me that, as the evidence at present stands, it is insufficient to justify a decision adverse to Mr. Darwin's theory as a general explanation."

Professor Bonney, in spite of his intention to present an absolutely unbiassed expression, has, in common with most geologists not familiar with coral reefs, retained the view of the correctness of Darwin's theory.[2] It can scarcely be said that the earlier examinations of coral reefs were made with the detail which has characterized the later explorations. The original work of Darwin was limited to a narrow field, and supplemented by data derived from charts and descriptions. Its correctness depends wholly upon the existence of masses of coral reefs of great thickness, where coral reefs exist as barrier reefs or atolls, and having assumed this the rest naturally followed. For no one will deny that subsidence is one of the possible modes of formation of masses of limestone of great thickness. But subsequent observers showed most distinctly that both atolls and barrier reefs occurred in regions of elevation. These exceptions are not limited to a single area. They occur in regions of the globe widely separated. While it undoubtedly is true, as remarked

[1] *Loc. cit.*, p. 332.

[2] Dana's support of Darwin's theory, based as it was upon very great experience among coral reefs, has probably been the principal cause of the general acceptance of the theory in late years, in spite of the attacks of recent investigators.

by Professor Bonney,[1] that Darwin has noticed most of the causes on which stress is laid by his critics, it should also be remembered that Darwin did not observe the phenomena subsequently examined, but merely suggested them as possibilities, and his critics may be excused for giving their observations a relatively greater value than to his theoretical views.

The whole argument of the great thickness of coral reefs based upon the analogy of the so called raised reefs of Cuba, described by Prof. Crosby and myself, or of the fossil reefs, is of little value, as it has been pretty conclusively shown that these elevated reefs, not only in Cuba but in the Pacific, are beds of tertiary limestone intercalated with beds of moderate thickness in which corals are found, and the same is true of older fossil reefs. Furthermore, these huge masses of tertiary limestone which form the substratum upon which both in Cuba and in the Pacific recent corals have found a footing, have played no part in the shaping of the barrier or encircling reefs, or atolls, which, as we have attempted to show, owe their origin in the main to mechanical causes.

Professor Bonney states that "Much stress is laid upon the fact that many coral islands afford evidences of a certain amount of upheaval; this amount, in most cases, is but slight, and its significance appears to me to have been exaggerated"; and he considers these indications to prove only oscillation. As far as the Fijis are concerned, the elevation extended over the whole group, and has been shown to amount to more than a thousand feet. In Australia it extended along the whole east coast of Queensland for more than a thousand miles, and was more than twenty-five hundred feet in height! He further says, "If the coral reef be only a sort of cap concealing a hill of pre-existent rock, we may reasonably be surprised that the 'ashlar rock' of coral limestone has in no case so far yielded to the action of the atmospheric agencies as to lay bare its inner support." We can answer this point most decidedly. In Florida the substratum underlying the recent coral reefs crops out at many places, and the highest points of some of the Keys consist of it. So do some of the hummocks in the southern part of the Everglades near Key Biscayne. In the Bermudas the greater part of the land of that group consists of the æolian rocks which underlie the recent coral reef. In the Bahamas the same is the case, and along the northern coast of Cuba the tertiary limestone forming the substratum of the recent reefs crops out in all directions, while in Australia rocks underlying the Great Barrier

[1] *Loc. cit.*, p. 324.

Reef can be traced as islands, islets, or negro-heads all along its line for more than a thousand miles. Finally, in the description of the islands of Fiji this substratum appears over and over again, either composed of volcanic rocks, or of great tertiary limestone banks. No better example can be found of the appearance of the substratum of the recent reefs than in Kaneohe Bay, Oahu, at the Sandwich Islands, where the reef is studded with islets and negro-heads consisting of volcanic rocks.

That corals grow in lagoons is well ascertained, and nowhere is it better seen than in Fiji, where nearly all the islands enclosed by barrier reefs are edged with fringing coral reefs. But why that should prevent a lagoon from being formed I cannot see. A lagoon is not bounded by a reef forming a closed wall rising well above the level of the sea. The greater part of the reef of many a lagoon of an atoll or barrier reef has from two to three fathoms of water upon it at high tide. The reef is also riddled on all sides with narrow channels or openings with from one to two fathoms or more at low tide, in addition to the wider and deeper passages to leeward, through which access is gained into the lagoon. But for all this the lagoon exists, while it may not have more than a few fathoms in maximum depth. This, however, does not prevent the coral heads on the inner slope of the reef from gradually becoming connected with the reef, and from encroaching little by little, but very slowly, upon the outer margin of the lagoon to a depth of seven or eight fathoms, at which the growth is checked either from the sediment accumulating on the floor, or from the strength of the currents scouring the bottom of the lagoon. The amount of dead coral which is ground up upon a reef flat is considerable. Much of it is cemented together and forms a breccia in the cavities of the coral heads, or in the open spaces between them. Still more of it is changed into sand and mud, which cover the floor of the lagoons of barrier reefs and of atolls, and finally a quantity is carried off in solution after the dead coral has become thoroughly rotten and crumbling.

Darwin also visited the western side of Mauritius, where, he says:[1] "It is probable that a reef on a shelving shore, like that of Mauritius, would at first grow up not attached to the actual beach, but at some little distance from it; and the corals on the outer margin would be the most vigorous. A shallow channel would thus be formed within the reef; and this channel could be filled up only very slowly with sediment,

[1] Darwin's Coral Reefs, 3d ed., 1889, p. 72.

for the breakers cannot cut on the shores of the island,[1] and they do not often tear up and cast inside fragments from the outer edge of the reef, while every streamlet carries away its mud through breaches in the reef. . . . A fringing reef, if elevated in a perfect condition above the level of the sea, would present the singular appearance of a broad dry moat bounded by a low wall or mound."

Darwin, when meeting Semper's objection that the existence of atolls or barrier reefs in a region of elevation was a fatal argument against his (Darwin's) views, is obliged to say that therein "seems to me no improbability in their having originally subsided, then having been upraised . . . and again having subsided."[2] He further says, "The existence of atolls and of barrier reefs in close proximity is manifestly not opposed to my views." Certainly not, but their existence in an area of elevation as claimed by Semper is. Darwin also says that, "When the land is prolonged beneath the sea in an extremely steep slope, reefs formed there during subsidence will remain closely attached to the shore, and will be undistinguishable from fringing reefs."[3] This seems to me impossible. The disintegration of the inner edge of the fringing reef, the action of the sea upon this disintegrated material, the solvent action of sea water, all will tend to form a channel between the outer parts of the reef and the shore, as is evidently the case in almost all fringing reefs, which show either an incipient channel where boats may circulate at high water, or a belt of considerable width in which the coral fringing the land has been killed by the silt brought down from the adjacent slopes, and has been decomposed, and, crumbling to sand or mud, is gradually being carried off at each high tide, forming a channel which when wide enough and deep enough becomes sufficiently prominent to change the fringing reef into a barrier reef.

The difficulties encountered in attempting to meet the many suggestions made by Darwin regarding reefs which he did not examine are well exemplified in the account which he gives of Rose Island, one of the Samoa group.[4]

[1] This would depend upon the width and slope of the fringing reef. Many of the narrow fringing reefs in Fiji have a uniform slope towards the lagoon, and do not present the structure described by Darwin.

[2] Darwin's Coral Reefs, 3d ed., p. 228.

[3] Ibid., p. 229.

[4] Ibid., p. 212: "The lagoon is very shallow, and is strewn with numerous large boulders of volcanic rock." (Negro-heads, A. Ag.) He further says: "This island, therefore, probably consists of a bank of rock, a few feet submerged, with the outer margin fringed with reefs. Hence it cannot be properly classed with atolls,

Bonney[1] similarly takes Dana's account of the eastern half of the Fiji Archipelago, as if it were based upon actual observations. Dana did not visit that part of Fiji, but derived his information from the surveys of these islands made by the officers of the United States Exploring Expedition. His statements are derived from the charts.

TRACK OF THE "YARALLA."

The track which we followed (Plate 1) was so arranged as to include for our first trip one or two of each type of island, and of the different types of atolls and barrier and fringing reefs in the group. Starting from Suva the day after our arrival, we visited Mbengha, returned to Suva, and went in the following order to Ovalau, Wakaya, Makongai, and Koro, skirted along the western shores of Taviuni, examined the northeastern coast of the same island, passed out through the Matangi Passage to Motua Levu and Motua lai lai, and skirted along the western extremity of the Nanuku reefs. From there we steamed to Wailangilala, where we landed our boring apparatus and the crew of whites and of natives needed for working the same. We then turned north, passing close to Nuku Mbasanga and Adolphus Reef, and entered Ngele Levu Lagoon. We next examined the Ringgold Islands, paying special attention to Thombia in Budd Reef. From there we returned to a former anchorage off Thurston Point on Taviuni, and followed much the same track back to Wailangilala, where we found our boring party settled and at work. We then steamed south, examining Williamson Reef, the Kimbombo islets, Bell Reef, and entered the Vanua Mbalavu Lagoon through the Ngillangillah Passage. Passing out of the lagoon by the Tonga Pass, we touched at Mango, Tuvutha, Naiau, and Lakemba. We steamed past Aiwa, entered the Oneata Lagoon, visited Thakau Lekaleka, touched at Mothe, entered the Komo Lagoon, the Yangasá Cluster, and the Ongea Lagoon. We passed by Fulanga close to the entrance, which was too

in which, as we have reason to believe, the foundations *always lie at a greater depth* [The Italics are mine. — A. AG.] than that at which the reef constructing polyps can live." Yet Dana and Wharton, as well as Krämer, say that it is an atoll, and the charts show it to be an atoll fully as much as any similar island in Fiji. So that if the islands in Fiji which resemble it, and which according to Dana and my own observations are atolls, yet according to Darwin they would not be so regarded, we shall have to seek for an atoll answering his requirements outside of the Fiji group.

1 *Loc. cit.*, p. 310.

shallow to allow our vessel to enter, but near enough to get an excellent idea of its characteristic structure. We next touched at Kambara, anchored in the crater of Totoya, made for Moala, and thence for Solo Lighthouse, examined the North Astrolabe Reef, steamed through the Great Astrolabe Reef, coming out west of Ono, examined a part of the northern shore of Kandavu, and then made for Vatu Leile, returning to Suva. On our second trip we visited Ngau, Nairai, the Horseshoe Reef, Mbatiki, and, entering the Moturiki Channel south of Ovalau, examined the inner side of the barrier reef as far as Mbau, and explored the barrier reef from Moturiki to Suva. During our third trip we steamed along the southern coast of Viti Levu, going as far west as Nandronga. Skirting the reef as closely as was prudent, we were able to follow the changes of the great barrier reef of Viti Levu west of Suva as it gradually passes into a fringing reef and disappears off the Singatoka River, to reappear again, first as a fringing reef, next as a barrier reef extending beyond the Nandi waters to the west of Nandronga. We then paid a second visit to Vatu Leile, which we had not been able to examine properly owing to bad weather, and returned to Suva, having steamed a little over thirteen hundred miles.[1]

While we were exploring the reefs in the vicinity of Suva, the "Yaralla" made two trips in charge of Captain Thomson, one to the Nandi waters entering through the Navula Passage, extending as far north as the Waia Islands to the south of the Yasawa group; the other passing close to Vatu Vara, Yathata, and Naitamba, on the way to Wailangilala in order to bring back the crew left there to carry on the boring.

THE PELAGIC FAUNA OF FIJI.

I brought with me deep-sea tow-nets of the various patterns used by the Prince of Monaco, by Dr. Giesbrecht of the Naples Zoölogical Station, and by Hensen on the "National" Expedition, in order to compare their efficiency with the Tanner deep-sea self-closing net in use on the "Albatross," and which I have adopted on my various expeditions. Unfortunately, our time in Fiji was so limited and the conditions for towing at great depths are such, among so many intercepting islands, that the results likely to be obtained seemed to make it unadvisable to

[1] The Islands and Coral Reefs of the Fiji Group, by Alexander Agassiz, Am. Journ. Sci., Vol. V., February, 1898.

devote the time necessary for such a comparison. So nothing was done to test the comparative efficiency of the various deep-sea self-closing towing nets. When practicable we collected on the reef flats of various islands and atolls.

A number of hauls were made with the deep-sea Tanner net at several points in Fiji, such as the Strait of Somo Somo, off the Matangi Passage, off the west face of Nukusemanu Reef, off Blackswan Point, off the north point of Vatu Leile, across the eastern opening of Mbengha Passage, and off Suva Harbor. The depth at which we towed varied between one hundred and seventy-five fathoms and thirty fathoms to the surface. At the localities where each deep haul was made, a surface haul was also made. We were rather disappointed in the character of our catch. There were no great novelties; the number of Medusæ was usually quite small, but we obtained a large number of Crustacea.

The contents of the nets varied but little at the different localities. We obtained young Fishes, Fish eggs and Salpæ, Doliolium, Alcyopidæ, Copepods, Squillæ, embryos of Macrurans and Brachiurans, Sapphirina, Sergestes, Euphausia, several species of pelagic Macrurans, and Rhegmatodes, Halopsis, Agalma, the bell of a large Siphonophore unknown to me, Tamoya, many Diphyes, Ectopleura, Oceania, Berenice, Liriope, Polygordius, Tomopteris, Octopus, Mollusk embryos, Hyalea, Atlanta, Styliola, Tiedemannia, and other Pteropods. In fact, the pelagic fauna seemed singularly like that of the Straits of Florida, but far less abundant.

Mr. Mayer made also a number of surface hauls, and collected many species of Acalephs which had escaped the large tow-net, two species of a Rhizostome, a Eucharis, an Aurelia, and an Idya. The Sagittæ we collected were unusually large; Collozoon was quite abundant, and occasionally we collected Globigerinæ of a reddish tint, and other Foraminifera.

During our cruise we constantly passed long windrows of Algæ torn from the reefs, extended patches of a yellow Trichodesmium, and masses of leaves and flowers, and branches of all kinds of trees, floating at the mercy of the winds and currents.

It is interesting to note that the surface hauls made during our trip have developed the fact that the majority of the genera of Acalephs collected in Fiji belong to the same genera as those found on the east side of the Isthmus of Panama. The great geographical range in the Pacific of many of the genera of Echinoderms and of Crustacea as well as of Fishes found in the West Indies has already been noted. The collections of Acalephs made by the "Albatross" in 1891,[1] and those we have made in Fiji, show a remarkable similarity between the West Indian Acalephian genera and those of this part of the Pacific. We found in Fiji Linerges, Polyclonia, Aurelia, Halopsis, Tiaropsis, Gonionemus, Liriope, Bougainvillia, Eutima, Oceania, Aglaura, Eucharis, Idya, Agalma, two genera of Diphyes and Physalia, all genera occurring in the Gulf of Mexico. This will be brought out in greater detail by Mr. Mayer, who has in preparation a paper on the Acalephs of our Southern States, which will appear somewhat later than his report on the Acalephs collected at Fiji. This similarity will undoubtedly be found to extend to other groups of pelagic animals.

We were fortuuate enough to be at Levuka at the time of the appearance of the "Bololo." On the morning of the 17th of November we left the ship at three o'clock, bound for a spit named Bololo Point, about three miles south of Levuka. We had scarcely reached the spot when our guide put his hand in the water and pulled out one of the worms. In a few minutes the water was full of them, canoes put out from the shore, men, women, and children were wading on the reef exposed by the tide, with nets, and all kinds of utensils to catch Bololo. As the light increased, the Bololo increased, and at one time they were so plentiful that the water surrounding our boat must have been filled with them so thickly as to resemble vermicelli soup. A bucket put overboard seemed to contain nothing else. We made an excellent collection, and preserved a large number by different methods. We found, as we had expected, that their sudden appearance was connected with spawning; there were males and females swimming about full of eggs and of sperm. When in captivity they soon discharged these, the water became milky, and masses of dark eggs were left on the bottom of the dish. With the escape of the eggs came the collapse of the worm, and nothing was left but an empty skin scarcely visible. Thus the Bololo seems suddenly to disappear. The males are light yellowish brown, the females dark green. Their activity is something wonderful, and the bursting of the animal when it discharges its eggs is quite a peculiar phenomenon.

Dr. Woodworth made it an object to collect all the material that could be got together in regard to the Bololo, and he will prepare a paper on these interesting Annelids.

[1] Reports on the Dredging Operations off the Coast of Central America, Mexico, off the Galapagos, and in the Gulf of California, in Charge of Alexander Agassiz, by the U. S. Fish Commission Steamer "Albatross," in 1891, in command of Lieut. Com. Z. L. Tanner, U. S. N. — XXI. Die Acalephen, von Otto Maas, Mem. Mus. Comp. Zoöl., Vol. XXIII. No. 1, 1897.

CLASSIFICATION OF THE ISLANDS OF FIJI.

It will greatly facilitate understanding the relations of the islands and coral reefs of Fiji, if we follow in their description a classification which will bring together islands and reefs of identical or similar geological structure.

We may take at first such volcanic islands as Koro, Ngau, and pass to the larger islands like Taviuni and Kandavu, finishing that class of islands with descriptions of Mbengha, Komo, and the like. We will take up next islands and reefs composed wholly of elevated coralliferous limestones like Marambo, passing to such islands as Namuka, Ongea, Fulanga, and to such reefs as Wailangilala and Ngele Levu. Next the island groups in which we find both volcanic and coralliferous limestones, such as Lakemba, Mothe, Vanua Mbalavu, Kimbombo, and the like, the two large islands of Viti Levu and Vanua Levu being treated separately. This will be followed by an account of the islands and reefs we did not examine, and finally by a sketch of the atolls, the geological structure of which could not be determined, and which might owe their origin to banks of submarine erosion, derived either from volcanic or from elevated coralliferous limestone islands.

Undoubtedly the islands of Fiji, whether of volcanic origin or of limestone, would vary greatly in the height to which they had been elevated. Naturally, the volcanic islands would be denuded and eroded to a less extent than the limestone islands, and the comparison of the islands in Lau might give us some idea of the extent of this erosion and denudation. The volcanic islands, consisting mainly of breccia, are of course far more rapidly eroded than if they consisted of compact volcanic rocks.

Of course some of the islands which have been named here as volcanic or as composed of tertiary limestones may prove on more extended examination to be composite islands, and in the rapid visit made to some of the islands we may not always have discerned their most characteristic features. Yet in a general way steaming between the islands, one cannot fail to be struck with the totally different aspect of the volcanic islands and of the islands composed of elevated limestone. A mere glance is sufficient to distinguish the rounded and gradual volcanic slopes (Plates **46**, **51**, **57**, **58**) from the flat-topped summits and precipitous cliffs characterizing the limestone islands (Plates **75**, **76**, **79**, **86**, **88**, **90**).

Gardiner has, as we have, classified the islands of Fiji into elevated limestone islands, into elevated limestone and partly volcanic, and into volcanic,[1] a division which Lister had previously applied to the Tonga group. Gardiner was, as we were, struck with the difference in the physiognomy of the islands, the volcanic islands, with their gentle slopes, rounded summits, or conical peaks, being in striking contrast to the flat-topped hills with precipitous sides, and the glistening white cliffs of the islands consisting of elevated coralliferous limestones.

I obtained from various localities in Viti Levu specimens of the older crystalline rocks belonging to the same series, which, according to Wichman[2] and Horne, have a very considerable extension both in Viti Levu and in Vanua Levu. The tufas and conglomerates are in many instances fossilliferous, and are considered by Martin as tertiary, not older than miocene. Wichman concludes that the larger islands must have existed as a continent during mesozoic and palæozoic periods, and that oscillations of level only took place in latest tertiaries. From the specimens examined by him, Wichman also concludes that Kandavu, Ovalau, Ono, and some of the Exploring Isles consist principally of andesites and basalts, and their tufas. According to Horne, Taviuni is the only island of the group which is of purely volcanic origin. This certainly is not the case. I would mention, among others, Moala, Thombia, and Totoya.[3]

VOLCANIC ISLANDS.

Koro.

Plates 3[a], 19[a], Fig. 8.

Koro is one of the larger volcanic islands which has not been greatly affected by submarine erosion. It is about ten miles long with a northern face of five, the east and west sides run to a point. The shores, with the exception of the southern part of the west coast, which runs nearly north and south, are bordered by a fringing reef extending about a mile and a half from shore; on the east coast the fringing reef is cut into small incipient lagoons (Nangaidamu Harbor), and has several boat harbors, generally opposite the mouth of a small river. On the north coast the reef patches extend nearly four miles from shore, forming an

[1] Proc. Camb. Phil. Soc., Vol. IX. Part VIII. p. 457 (1898).

[2] Min. u. Petrog. Mittheil. v. Tschermak, Vol. V. Pt. I. p. 1 (1882).

[3] The specimens of rocks we collected in Fiji at the different islands are now under examination, and a report on them will follow later.

indistinct lagoon called Stone Axe Roads. The northeastern extension of the east coast fringing reef forms an open roadstead. This spur is covered with magnificient patches of coral in from one to three fathoms. One can trace from the long line of lava negro-heads — some of these are quite large — covering the reef flats, the former northern extension of the island. We could also trace to the south the low bluffs from the erosion of which have been formed the flats upon which the fringing reef has found a footing. A very strong current was flowing over the spur of Nathomaki Point, driven westward by the easterly trades.

The principal ridge of the island runs transversely across it from the southern point to its northeastern end. Its highest point is over 1,800 feet. The faces of the island are furrowed by deep valleys.

Mbatiki.

Plate 12.

We did not land on Mbatiki, but steamed close enough to the shores to obtain some idea of its characteristic features. The highest peak on the northern side is a little over 600 feet. There are two deep indentations, one on the west, the other on the south side. It is surrounded by a shore fringing reef from three points of which spurs extend parallel to the shore, impounding three narrow shallow lagoons with a depth of from three to five fathoms. The lagoons are full of coral heads. There are boat passes into two of the lagoons. The island is of volcanic origin.

Moala.

Plates 16, 57.

Moala is an island of volcanic origin, triangular in form, the eastern face indented by a deep bay, fully two miles long, by about three fourths of a mile in width, with sixteen fathoms in greatest depth. The highest point of Moala is over fifteen hundred feet. The ridges surrounding the deep bay have the appearance of being the rim of an extinct crater (Plate 57), broken to the eastward, some points of which rise from over twelve hundred to over fourteen hundred feet, the bay forming the bottom of the extinct crater.

The western part of the north coast is edged by a fringing reef extending nearly a mile off shore; towards the east the fringing reef proper becomes quite narrow, while disconnected coral patches of considerable width extend towards the northeast extremity of the outer reef. The outer reef flats are narrow, and run in a southerly direction, forming an elbow opposite the eastern point of the island at a distance of from one to two miles, and enclosing the lagoon off the eastern face of the island, the continuation of the deep bay. South of the deep bay the outer reef nearly connects with the edging reef of the island, leaving a passage

DEEP BAY, EAST FACE OF MOALA.

across the outer reef about a mile in width, the southern horn of which extends about three miles to the south, then in a westerly direction, then north until it strikes spurs of the fringing reef on the northwestern coast of the island, where the outer reef forms in connection with the fringing reef a series of reef flats full of coral patches and heads. The lagoon to the southwest of the island is also full of coral patches and heads, some of them of considerable size, which extend to Herald Roadstead, the northeastern part of the lagoon, which alone is comparatively free from obstructions. Owing to the presence of so many patches and heads the depth in the lagoon is most irregular. In Herald Sound it is as great as twenty-five fathoms, and somewhat less off the southwest and northern coasts. The characteristic heads which crop out from the shore at so many points are well illustrated by the heads composed of volcanic rocks which form the spit protecting the anchorage to the west of Naroi village, on the north shore of the island. Wherever we dredged we found that the bottom inside the lagoon consisted of fine volcanic mud mixed with coral ooze and broken shells.

There are two entrances to the lagoon on the east face, one opposite the deep bay, the other to the south, while on the west there is an entrance to Herald Sound (the lagoon of the southwest side of the island) near its northern extremity.

Ngau.

Plates 12, 13, 11a, Figs. 1-3.

Ngau Island is about eleven miles long, by an average of nearly four miles in width. It consists of volcanic rocks; a high ridge runs along the middle with spurs separated by deep valleys extending towards the east and west coast. One of these spurs forms a deep bay on the northwestern coast. The peaks of the main ridge vary in height from 1,000 to over 2,300 feet. Ngau is protected on the east and north by a broad fringing reef of a width of over three miles. At the northern extremity and on the east face there are a few reef boat harbors, cut out of the fringing reef which also extends along the whole western shore as a very narrow fringe. As will be seen from the chart (Plate **13**), the small reef harbors are without exception off the mouth of the mountain streams both on the north and east faces of the island; these in the rainy season bring down a large amount of mud and prevent the growth of corals at their mouth. From the southern end of the island extends in a northwesterly direction an outer barrier reef, varying in width from a quarter of a mile to three quarters of a mile. This reef is continuous being only broken in the middle by a narrow ship passage. The general depth of the lagoon is about twenty fathoms, with a greatest depth of twenty-nine. The western reef sweeps round the northern face of the lagoon, its eastern extension becomes broken into disconnected patches, and the greater part of the northeastern bay of the lagoon is filled with coral patches which connect it with the fringing reef of the north shore of the island. There are also numerous patches in the southern bight of the lagoon, and along the inner edge of the outer reef near the northwestern elbow of the reef. As far as we examined the reef of Ngau the reef flat was covered with most extensive patches of thriving corals.

There is a small island, Yathiwa, on the very edge of the reef forming the southern horn of Ngau. It holds to Ngau very much the same relation which Kobu Island does to Nairai, but is nearer the outer edge of the reef, while Kobu is in the lagoon surrounded by comparatively deep water.

Mambulitha Reef.

To the south of Ngau we could see the breakers giving the outline of Mambulitha Reef (Plate **12**), separated from Ngau by a channel having a depth of 750 fathoms. This reef is pentagonal in outline, about one mile and a quarter long, is awash, has no opening, and encloses a shallow lagoon of pale green water, the sea breaking heavily upon the edges. I consider this reef as having been denuded and eroded to its present stage, which precedes that of a more sunken atoll, like Adolphus Reef, with a deeper lagoon.

Nairai.

Plate 11ª, Fig. 4, and Plates 12, 14, 58, 59.

Nairai is a volcanic island, triangular in shape (Plates **12**, **14**), with sides of about four miles in length. Its central ridge forms an open arc to the east, its central peak rising to a height of over eleven hundred feet The western slope of the island is much less steep than the eastern side. (Plate **58**.) The island is edged by a narrow fringing reef, with the exception of the most western point, where it expands into a broad fringing reef, the outer patches of which extend into the outer encircling reef. The encircling reef surrounding the island is a narrow reef flat, from a quarter to a mile distant from the eastern side, and from one to one and a half on the western side. But the prolongations of the horns of the outer reef to the northeast, south, and west are from four to five miles distant, forming thus three lagoons separated by long passages. (Plate **14**.) The greatest depth in the lagoons is twenty-six fathoms off one of the western passages. The general depth is from ten to fifteen fathoms. The inner edge of the eastern outer reef is fringed with coral patches. This part of the reef is continuous, having only one boat entrance nearly opposite the southern extremity of the island. The western reef has two deep passages, and a boat passage near the southern horn of the atoll. This as well as the other points of the outer reef, both at the northeastern and northwestern horns, are studded with coral patches. The greater part of the lagoon, extending from the northern part of the island to the Nayatha Passage, is studded with rocks and coral patches, undoubtedly the remnants of fragments of the main island, which crop out in every direction within the lagoon, and as negro-heads upon the reef flats. Naikobu (Plate **59**), or Magnetic Island, a small island to the south of Nairai, is one of these outlyers; it is ninety feet in height, the base running into ten fathoms, and is covered with corals. It is further remarkable for the great variation it causes to the compass. We observed on the top a westerly deflection of 87°. The bottom of the lagoon consists of fine coral, coralline sand, and broken shells, which form large white areas separating the coral patches and the numerous patches of coralline algæ which flourish upon the floor of this lagoon wherever we examined it. The corals of the fringing reefs of both Nairai and Ngau were growing specially vigorously.

Makongai and Wakaya.

Plates 3[a], 11[a], Fig. 9; Plates 3[a], 11[a], Figs. 7, 8, and Plates 15, 55, 56.

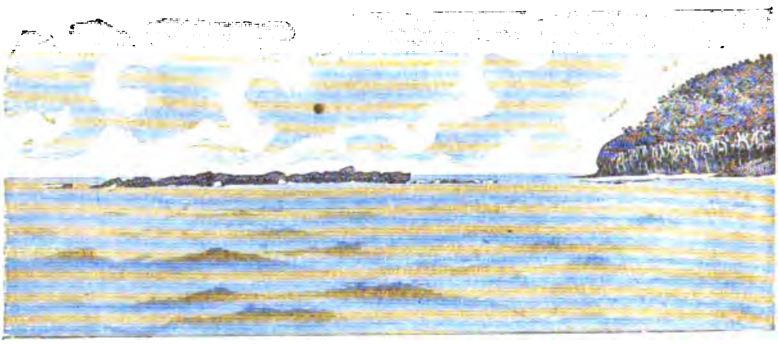
Makongai and Wakaya present features nearly identical. They are both long lines of narrow reefs, enclosing in the one case an irregularly triangular lagoon open on its northern face, and in the other an irregularly shaped parallelogram, with undulating sides and rounded corners. The island of Makongai is somewhat rectangular, with many indentations; it is of volcanic nature, and attains a height of nearly 900 feet. On its eastern face the encircling outer reef becomes its fringing reef at several points. It is separated by a narrow channel having a depth of twelve fathoms from Makondranga, a small island similar in structure to Makongai, about half a mile from the outer reef. The whole eastern encircling barrier reef is broken up into a number of small patches with boat passages between them. With the exception of one boat passage the western reef forms a continuous line of breakers, but on the northern side the reef patches are limited to rocks, grown over

NORTHWEST POINT OF MAKONGAI.

LEDGE OFF MAKONGAI.

at the base with corals, judging from those we saw while passing into the lagoon.

Makongai is edged with a fringing reef. The islands in the Makongai lagoon are in the northeast corner close to the eastern face of the outer reef. The lagoon has a general depth of from thirteen to seventeen fathoms, with a greatest depth of twenty-one fathoms in the northern part. The southern part of the lagoon is full of coral patches, remnants of islands and islets similar to those of the small island of Tambaka, still connected with Makongai by a neck of boulders, which reaches to the westward as an extensive flat, and fringed below low water mark with flourishing patches of corals. Such a patch with a few angular blocks



LEDGE OFF MAKONDRANGA.

still visible above high water mark, lies off the southwest point of Makondranga, and many others off the southeastern face of Makongai. Corals within the lagoon grow in from seven to one or two fathoms. The rest of the bottom of the lagoon consists of coral and coralline sand.

Makongai and Wakaya are connected by a narrow reef ridge about a mile in length. The island of Wakaya is nine miles long, triangular in shape, tapering to a point, and situated close to the western edge of the outer reef of the lagoon. A fringing reef edges its eastern face, while the extension of the outer reef forms the wider fringing reef of the western shore. Towards the south this part of the fringing reef encloses two secondary lagoons, one of which has a depth of five fathoms. The southern part of the outer reef is continuous; the northeastern face is broken by several passages, and there are three to the north of Wakaya on the western face. The highest point of Wakaya is nearly 600 feet, forming a range of steep bluffs along the northern part of the island, which slopes very gradually to the east. The southern part of the island is not more than 300 feet high, and is joined to the rest of the island by a comparatively low neck. The depth of the Wakaya Lagoon is greater on the average than that of Makongai; it reaches a maximum depth of thirty-six fathoms, with a general average depth of over twenty. There are comparatively few patches in the lagoon. The bottom consists of coralline sand and shells. We entered through the northern passage and crossed the lagoon, and on our way out examined the reef patches forming the boat passages to the south of it. On the shore of the bay, near the boat passage, we found a good deal of pumice. We found traces of elevation on the neck connecting the point on which Lieutenant Langdale's house is built.

We could not examine the corals on the weather face of the weather reef, but on the inner side and on the lee reef we found corals flourishing most luxuriously, mainly Madrepores, Pocillopores, Astreans, Mæandrinas, Fungiæ, and a few Gorgonians. They form a belt mainly between two and seven or eight fathoms, beyond which there seem to be only coral sand and corallines both on the inner and outer faces of the lee reef. With the disappearance of Wakaya through denudation and erosion, we should have an atoll with a substratum of volcanic rocks which very likely might be covered to a limited depth with islets of coral sand blown up from the encircling reef, — an atoll in no way to be distinguished by outward appearances from the theoretical atoll built up by corals and by subsidence.

Mbengha.

Plates 8, 11ª, Fig. 5, and Plates 46–49.

Mbengha Island is irregularly shaped, with three deep indentations, one on the western side, the others on the eastern, nearly cut off the high point forming the eastern side of Malumu Bay from the main body of the island. (Plate 48.) The principal ridge, running nearly north and south across the central part of the island, rises abruptly from the south to a height of over a thousand feet, and has several peaks attaining heights varying between 1,200 and over 1,400 feet. The secondary ridge to the east of Malumu Bay is somewhat less than a thousand feet. On the east face to the south of Solianga are exposed some fine bluffs consisting of volcanic conglomerate breccia. (Plate 46.) They are perhaps as good examples as we have seen of the great erosion and denudation which have taken place in this part of the Fiji group.

A more detailed view of the appearance of the volcanic rocks of Mbengha is given in Plate 47, an eroded shore bluff immediately in the rear of the beach at Rukua on the west side of Mbengha. Similar volcanic breccia bluffs are characteristic of many points in Fiji.

In adition to the main island there are three other islands. Moturiki and Stuart, which are small satellites of Mbengha, and Yanutha, a larger island near the western edge of the lagoon. These islands have the same geological structure as that of Mbengha. (Plate 8.)

Mbengha is on the eastern point of the lagoon, separated from the inner edge of the outer reef by a channel varying in width from a half to one and a quarter miles, with a greatest depth of twenty-three fathoms closer to the island than to the reef. The channel between Yanutha and the outer reef is about three quarters of a mile in width, with a depth of from eleven to thirteen fathoms. There are in addition a number of patches of coral rising from a depth of from ten to twelve fathoms, irregularly scattered over the western part of the lagoon and along the inner edge of the outer reef.

Mbengha and Yanutha Islands are enclosed within a long reef over thirty miles in length, forming an irregularly shaped pentagonal lagoon with rounded angles. The northern side is open, forming a passage fully five miles wide, and studded with patches. This part of the lagoon slopes very gradually from 17 fathoms to 130 or 140 fathoms in the centre of the Mbengha Passage, separating Mbengha from the island of Viti Levu.

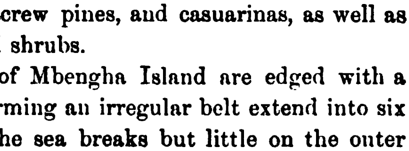
The northeastern face of the lagoon is flanked by the Pratt Reefs, those upon which the low sandy Storm Island is placed, and the Nanuku Reef. There are several passages available for vessels on that side of the lagoon. The Nanuku, Sulphur, and Cutter Passages with a depth of from nine to thirteen fathoms. The southern and southwestern sides of the lagoon are flanked by a long unbroken coral reef, the Mbengha Barrier Reef, varying in width from half a mile to over a mile and a quarter, extending from Cutter to Frigate Passage. There is a small sand key about the middle of the Mbengha Reef on its inner edge. To the north of Frigate Passage the Yanutha Reefs form the northwestern side of the Mbengha Lagoon. They are separated by broad channels ending in the reef of Bird Island and a long line of patches, the Nisithi Rocks, which form the western spit of the wide opening on the northern side of the lagoon. As will be seen from the chart, the bottom of the Mbengha Lagoon is most irregular; it is very uneven, varying greatly in depth, and full of heads and patches overgrown with corals. The rocks and heads and patches are fragments of volcanic rock, the remnants of the island of Mbengha when it extended over the greater part of the area now enclosed by the outer reef,

— remnants left from the disintegration and erosion of the former greater Mbengha.

The bottom in the lagoon is a mixture of volcanic mud and coral sand in the vicinity of the islands, but as we proceed towards the reef it carries a greater admixture of coralline algæ and of coral sand, and in the belt adjoining the inner edge of the outer reef is made up entirely of fragments of coral, of coral sand, and of coralline algæ. In the central parts of the lagoon it is algæ and corallines.

The reef rises very gradually from seven fathoms to a depth of from two to three feet on the reef flat. This is covered with fragments of dead corals which increase in number towards the sea edge of the reef. The fragments are covered with algæ, corallines, and nullipores, which cement them together. In depths of seven to eight fathoms heads and clusters of corals begin to grow. They are separated by wide lanes of coral sand, and as we rise on the slope of the reef they grow more closely, forming a wide belt of thriving corals from six to three or two fathoms in depth, when they grow less profusely, and finally pass into the wide flat area of the outer reef, made up of broken corals and fragments, and large masses thrown up on the sea face of the reef, which are gradually being broken up by the surf beating upon the reef flat.

Storm Islet[1] (Plate 49) is an excellent specimen of a sand key thrown up by the waves upon the outer reef flats. It is somewhat less than three hundred yards long and about eighty yards wide. The beach is quite steep, protected by large patches of beach rock, which surround the southern extremity of the island. The crest of the island is covered with cocoanut trees, screw pines, and casuarinas, as well as with an outer fringe of bushes and shrubs.



STORM ISLET.

The greater part of the shores of Mbengha Island are edged with a fringing reef, and coral patches forming an irregular belt extend into six or seven fathoms in depth. As the sea breaks but little on the outer

[1] Dana has called attention (Coral Islands, p. 241) to the advantage which coral island accumulations have over other shore deposits, "owing to the ready agglutination of calcareous grains," and, as he suggests, with the formation of coral sand rocks along the beaches and reef rock in the water a rock defence against encroachment is produced. So that limestone rocks thus formed will prove a most effectual barrier to the destructive action of the waves.

Mbengha Reef, I was able to examine the sea face of the reef, and found that in Frigate Passage both sides of the reef were flanked with large heads of corals beginning in from five to seven or eight fathoms. On the outer face, though corals were growing, there were no large heads, at about six fathoms we found Madrepores, Fungiæ, Pocillopores, small heads of Porites, Astreans, and of Mæandrinas and Gorgonians. This belt extended to the line of breakers pounding upon the reef flat. Outside of six to eight fathoms the corals seem to have disappeared, as the lead brought up nothing but coral and coralline algæ sand.

Kandavu.

Plates 10, 11, 50.

The extent of the erosion and denudation which has taken place along the coast of Kandavu is well exemplified by the John Wesley Bluffs near the village of Tavuki (Plate **10**), and similar bluffs rising to the westward of Tavuki Bay. The John Wesley Bluffs (Plate **50**) are a line of nearly vertical cliffs of volcanic origin cut into wide rounded lamellar masses, rising to a height of fully 500 feet on the east side of Tomba ni Tavuki. A part of the hill slopes on the west side of the bay are covered by the rounded tops of similar rocks cropping out on the surface, giving the slope the appearance of a graveyard crowded with dome-shaped monuments.

The heads studding the Bay of Tavuki, and forming the extension of the outer reef patches parallel to the coast, are covered with thriving corals, growing upon a substructure of volcanic rocks, as is clearly seen from the nature of the negro-heads cropping out in the bay.

With the exception of the broad fringing reef stretching to the west of Tavuki, the north shore of Kandavu is edged by a narrow fringing reef (Plate **10**), and from Yale Point to Tomba ni Richmondi an indistinct barrier reef extends, made up of small distant patches, except where the Malatta Reefs enclose a wide bay north of John Wesley Bluffs, studded with coral patches and heads. The south shore of Kandavu is likewise edged with a narrow fringing reef in Soso and Kandavu Bays inside of the broad barrier reefs across their entrance. The islands and islets within the North Astrolabe Reef Lagoon are also edged with narrow fringing reefs.

The platform of submarine erosion extending north of the eastern extremity of Kandavu is one of the best examples of its kind we find in Fiji. The great lagoon, with its islands and islets, represents a stage of denudation and erosion somewhat more advanced than that existing on the eastern half of the south shore of Kandavu.

We cannot fail to notice also the greater width of the shore platform wherever the coast has a northerly trend, as, for instance, west of Tomba ni Richmondi on the north coast, and north of the John Wesley Bluffs, where the platform is edged by the Malatta Reefs and studded with heads and patches. On the northern coast, however, the fringing reefs are narrow, while on the south coast of Kandavu (Plate 10) they take their greatest development, exposed to the full sway of the southeast trades. A glance at Plate 11 cannot fail to show the relatively great width of the eastern belt of the encircling reef, as compared with that of the western side of the Great Astrolabe Lagoon.[1] In a smaller lagoon like North Astrolabe Reef, where the breakers pour over the eastern face, and water flows constantly over the western edge, the difference in the width of the reef on the two sides is not so marked.

While undoubtedly the width of a reef depends in great measure on the nature of the platform upon which it grows, yet I do not see the force of Lendenfeld's statement,[2] that while "lateral growth of corals no doubt takes place, it is not the actual cause of the formation of the great coral reefs." There certainly is nothing to prevent the swarms of embryos which float at certain times in the vicinity of a coral reef from attaching themselves and growing upon any surface within reach having the proper depth on both sides of any growing reef. Undoubtedly the extension within the lagoon, both in barrier reefs and atolls, of the coral heads is due to such a cause, and the wider the reef the closer do the heads come together as we pass upon the reef flat from the inner edge of the reef towards the outer margin. In an account of a discussion on coral reefs[3] by Sollas, Hickson, Rothpletz, and others, Stebbing stated that young corals might start on either rising or subsidence, but only subsidence is favorable. That, it seems to me, depends entirely on the depth at which they start; they may have 120 feet, and build up a reef of that thickness, which is fully as thick as most reefs we know anything about.

[1] I cannot agree with Gardiner in his statement that the windward reefs of Fiji are of about the same breadth. (*Loc. cit.*, p. 492.) Compare the windward reefs of Mbengha, of the Great Astrolabe Reefs, and of the east coast of Viti Levu with the windward reefs of Wakaya, of Nairai, of Totoya, of the Budd Reef, of Kanathea, of the Exploring Isles, of the Argo Reefs, of Lakemba, of Aiwa, of Mothe, and of Ongea; the latter are certainly as a rule much narrower than the former.

[2] Nature, Vol. XLII. p. 31.

[3] Nature, October 12, 1893, p. 575.

Murray,[1] who visited Kandavu in the "Challenger," considers the banks of Fiji surrounding the extremities of volcanic islands as banks formed from the loose material of the islands spread out laterally by wave action, the extensive banks extending much farther seaward there in one direction than in another. Murray has also called attention to the North Astrolabe Reef, which, if its present condition with Solo Rock in the centre is due to subsidence, should have a very much deeper lagoon, instead of the comparatively shallow one characterizing that reef.

Great Astrolabe Reef.

Plates 11, 11ᵃ, Figs. 10-13, and Plates 51, 52.

To the northward of the eastern extremity of Kandavu (Plate **11**) extends the Great Astrolabe Reef. Its eastern face is the extension of the reef to the eastward of Tomba ni Soso (Plate **10**), an irregularly shaped bay, the mouth of which is protected by a barrier reef. This barrier reef extends as a fringing reef along the southern coast as far as Kandavu Bay, where it becomes separated from the island and forms stretches of barrier reef patches, with passages leading into the bays protected by the reef.

West of the entrance to Ngoala Harbor a broad fringing reef extends along the southern coast nearly to the western spit of Kandavu. Several reef harbors are cut out from it, one of which, Tomba Yauravu, is of considerable size (Plate **10**). From Naingoro Pass the outer reef of the Great Astrolabe Reef runs unbroken in a northerly direction for a distance of 25 miles round its northern horn, as far as Usborne Pass, which is an entrance into the lagoon on the western side, about a mile from the apex of the Great Astrolabe Reef. Off Mbulia, the easternmost of the islands inside the Great Astrolabe Reef, the eastern encircling reef makes a sharp elbow, and then forms a double curve in a northwesterly direction to the narrow apex, from which the reef turns sharply south as far as Alacrity Rocks in a great narrow arc broken in many places. North of Ono Island there are three well defined passages, but south of Alacrity Pass the reef becomes much broken up into small patches, and finally, from Ono Island south the lagoon is open, and has a steep slope towards the 100 fathom line.

The depth of the lagoon north of Ono is not more than twenty-two fathoms; the bottom is most uneven, often passing rapidly from five

[1] Nature, July 4, 1889, p. 222.

or eight fathoms to seventeen and eighteen fathoms, with a number of extensive patches, the remnants of former islands now covered with coral. (Plate 11.)

Within the Great Astrolabe Reef are included a number of islands and islets. They are all volcanic in structure, and all bear signs of the great denudation and erosion to which they have been subjected. Beginning at the north there is Vanua Kula, about 250 feet in height, covered by scanty vegetation; next comes Ndravuni, a much larger island, rising to a height of 350 feet. Yanu Yanu sau and Yanu Yanu eloma are small islets upon a spit which must have formed a part of

NMARA AND YANU YANU ELOMA.

Nmara Island; to the south of it is Ngasi Mbali. To the eastward are Yaukuve and Yaukuve lai lai (Plate 52), 400 and 200 feet respectively, connected by a spit, and off the south point of Yaukuve lai lai extends a long sunken shallow rocky spit. Mbulia and Yambu are to the north of Ono, the largest of the islands within the Great Astrolabe Lagoon (Plate 51). It has two peaks of over 1,100 feet, and is indented with deep bays forming finger-like spokes, which further disintegration would soon separate as distinct islands, similar to those of Vuro and Vuro lai lai off the northeastern point of the island. Between Ono and the eastern point of Kandavu Island the lagoon is dotted with numerous rocky and coral patches. Ono, and most of the islands of the Great Astrolabe Lagoon, are edged with fringing reefs. The eastern reef flat is quite broad (Plate 11); in some localities it is nearly a mile wide, besides being fringed along the inner edge by nearly continuous patches of rocks and corals. On the western face of Ono there are some fine cliffs, interesting as showing the progress of the denudation and erosion to which the island has been subjected. It seems comparatively simple to follow with the chart the changes which must have taken place in separating from Kandavu the islands enclosed within the Great Astrolabe Lagoon north of that island. They undoubtedly represent the fragments of the former northern extension of Kandavu itself, which probably covered the greater part of the area now enclosed by the Great Astrolabe Reef.

If we examine Kandavu Island itself (Plate 10), we can easily see how far denudation and erosion, if continued, would cut it up into a number of larger or smaller islands; as, for instance, an island would be formed at the neck separating Tomba Kaivala from Koro Levu, a larger island, by the cutting of the neck separating Tomba ni Ndaku on the north side from Tomba ni Soso on the south of the island. Finally, the cutting of the Malatta Isthmus would make two islands of considerable size of the western half of Kandavu, while the many spits bounding the deep bays of the island would also become islands similar to Matanuku on the south side of Kandavu, and connected with it by the broad fringing reef. These would all be enclosed on the south by the southern extension of the Great Astrolabe Reef, which is now either a barrier or a fringing reef along the south coast of Kandavu, while on the north coast the island would merely be flanked by outlying reef patches separated by great stretches bare of reefs, as along the southwestern part of the Great Astrolabe Lagoon.

Skirting the northern shore of Kandavu from Tomba Kaivala to Levuka, we found the physiognomy of the larger island to be identical with that of the islands of the Astrolabe Lagoon, — high cliffs, formed by the crumbling of the faces of the shores, sloping to high mountains, deep bays extending far inland, and a vegetation identical with that of the adjoining islands. According to the position and proximity of the islands to the inner edge of the outer reef flat, we found the bottom of the Great Astrolabe Lagoon to consist of volcanic mud or of coral sand and coralline algæ, or of a mixture of the two.

North Astrolabe Reef.

Plates 11, 11ª, Fig. 14, and Plates 53, 54.

North Astrolabe Reef is separated from the northern point of the Great Astrolabe Reef by the D'Urville Channel, which is about a mile wide, and with 190 fathoms coralline bottom in the middle (Plate 11).

North Astrolabe Reef encloses an oval egg-shaped lagoon about four miles in length by three and a half in breadth, with a small rocky islet, Solo, situated nearly in the centre of the lagoon (Plate 11). The greatest depth of the lagoon is sixteen fathoms, with very undulating bottom full of rocky and of coral patches along the inner edge of the reef, and especially over the southern part of the lagoon. Solo is composed of volcanic rocks, and has been very much eroded by the action of the sea (Plate 54). Corals grow upon its slopes, but they are not very flourishing, either there or upon the many patches found inside the lagoon, and which are separated by broad sand lanes, or by dark patches of nullipores and algæ, with a few scattered coral heads.

The reef enclosing the lagoon is continuous except on the north side, where there are two entrances into the lagoon, one with thirteen and the other with three fathoms in the channel. The inner side of the weather reef can be reached quite close to the breakers. There is from one and a half to two fathoms of water on the reef flat, which is covered by a great number of flourishing patches of coral, mainly Madrepores, Pocillopores, heads of Astreans and Mæandrinas, with a few Gorgonians. The patches are separated by wide areas of coral and coralline sand. Towards the inner part of the lagoon, as the water deepens, the coral patches are separated by masses of dead corals and of fragments. Dark patches of coralline Algæ become more abundant, and the coral patches less flourishing and more distant. On the outer edge of the reef, to the south of Beagle Passage, the reef flat is somewhat narrower than on the eastern face, where it varies from 1,000 to 1,800 feet in width; it is covered by one to two fathoms of water, and the coral patches appear to flourish upon its surface fully as luxuriantly as upon the eastern face. The corals descended in steps to ten or even eighteen fathoms, rising from the coral and coralline sand separating the heads. They were most flourishing in the belt of from six to ten fathoms in depth. The prevailing trades drive a strong current across the lagoon, and the water of the lagoon rushes out through the northern passages and over the western reef flats with considerable velocity. The bottom inside of the lagoon consists mainly of algæ, of coralline algæ, and of broken shells and fragments of coral.

It is quite probable that the North Astrolabe Reef represents an eroded peak adjacent to the former greater Kandavu, of which Solo Rock is the only witness left (Plate 53).

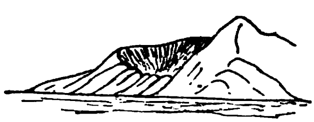
Budd Reef.

Plates 4, 18, 70.

Budd Reef (Plate 18) has a narrow outer reef of irregular shape, broken into many separate patches. These become quite distant on the southern side, leaving the outline of the reef indistinct. The lagoon, as well as the channels separating the islands enclosed within the outer reef are quite deep, with the exception of that part of the lagoon which lies south of Yambu and Yanutha and between Thombia and the northwestern edge of the outer reef. The deepest part of the lagoon is 47 fathoms and the average depth is between 35 and 40 fathoms.

In addition to Thombia, which is on the northern horn of Budd's Reef, there are the islands of Yanutha, Yambu, Mungaiwa, Tai ni Mbeka, and Rara ni Tinka, which are in the central part of the lagoon. South of the central islands the lagoon is also studded with rocks, as well as in the southwestern horn of the lagoon. The islands and islets and rocks, as well as many of the patches, are of volcanic origin. Yanutha, the largest of the islands, about a mile long and half a mile wide, rises to a height of 480 feet. It is connected by a coral reef with Mungaiwa Island and Mbeka Rock.

The most interesting of the islands is Thombia (Plate 70), the crater of an extinct volcano, having an exterior circumference of about two miles. The crater is half a mile in diameter, with a greatest depth of twenty-four fathoms. The rim of the crater rises at its highest point in a dome of nearly 600 feet. On the northeast side the horns of the rim are connected by a flourishing fringing coral reef about a fifth of a mile in length, the extension on the ridge connecting the horns of the fringing reef surrounding the island. Both the inner and outer slopes of Thombia are steep, and, except on the northwest side, we find over thirty fathoms within a short distance of the shore.



WESTERN END OF THOMBIA.

One cannot fail, on seeing the coral reef growing on the denuded rim of Thombia with the enclosed deep lagoon having a depth of twenty-four fathoms, to revert to the old opinion that some of the lagoons of atolls represented the rim of extinct craters. There is, it seems to me, nothing unreasonable in the suggestion that many of the small round atolls, or others perhaps rising from great depths and isolated, represent the denuded rims of such extinct craters as Thombia, or it may be that, if of greater size, they may represent parts of such larger craters as Totoya, or of circular islands with interior lagoons resembling extinct craters, like the Sound of Fulanga. It seems simple to imagine that, when these small extinct craters have been levelled down, and corals have obtained a footing, they may have formed such atolls as Pitman's Reef, Motua Levu, Motua lai lai, Williamson Reef, Horseshoe Reef, and other similar atolls in Fiji. We must remember, however, that the formation of such atolls may also be accounted for as the result of the denudation and submarine erosion of a patch of elevated limestone, cut first into a sound, and then, with the disappearance of the outer rim, into a lagoon surrounded by a shallow reef flat; or the same result may be accomplished from the wearing away of islets of volcanic origin enclosed within the outer reef, as, for instance, from the disintegration of the islets now left in such atolls as the Kimbombo Islands, Komo, and others, or of islets consisting of elevated limestone like the Aiwa Islands, Katavanga, Vekai, and others. The structure of the negro-heads occurring upon the outer reef flats, or their position near either a volcanic or an elevated reef region being the only guide as to the category to which belong such atolls as Thakau Mata Thuthu, Thakau Vutho Vutho, the Adolphus Reef, Dibble's, Duff, and Bell Reefs, Thakau Tambu, Malevuvu, etc.

Such a cluster as Budd Reef suggests an explanation for the formation of interior atolls, like those described by Darwin as occurring in the Maldive Islands, very different from the one suggested by him. Were Thombia cut down by erosion to the water's edge or below, and changed into a small atoll, we should have a secondary atoll within the area enclosed by Budd Reef, and were the other small islands of the cluster summits of elevated limestone, and should they in their turn be cut down, they might form in such a large lagoon as that of Budd Reef other diminutive atolls, or small atolls enclosed within an atoll. Such interior atolls, if my view of the formation of atolls is correct, could only be formed in lagoons of considerable depth and size, so that the seas formed by the prevailing winds should have a long sweep and rise to a considerable height, and thus possess great disintegrating power. I shall refer again, when describing Vanua Mbalavu, to the probable origin of such great depths as forty-seven fathoms inside of the reef encircling the islands of Budd Reef.

Komo.

Plates 19[a], Figs. 9-11, and Plates 22, 63-65.

Komo Island is a narrow ridge of volcanic origin, about a mile and a half in length, rising to over two hundred feet. Its western extremity is connected by a coral reef full of volcanic negro heads, two of which are mushroom-shaped and of considerable size, with the islet of Komo Ndriti, itself about seventy feet high. Komo lies in the southeastern horn of the lagoon (Plate 22) close to the southern face of the outer reef flat, from which it is only separated by a narrow boat passage full of negro-heads, especially numerous off the southeast point of the island. The lagoon enclosed by the outer reef flat is elliptical. There are two ship passages through the north face of the outer reef. The northern and eastern reef flats are narrow, edged on the outer side by masses of negro-heads; while the western and southern reef flats are fully half a mile broad, and edged by an inner belt of heads, the central part of the lagoon is quite clear of them. The rocks were composed of a volcanic puddingstone (Plate **64**), much like that of Mbengha, Levuka, and elsewhere. This disintegrates readily, is easily undercut, as we had ample proof in the undermining of the shore bluffs and the formation of so many negro-heads on the reef flats and off the spits of the island (Plate **63**). The aspect of the islands of volcanic origin and of elevated limestone is quite different as seen from the sea. The mode of disintegration and erosion of the two kinds of material can at once be distinguished from the peculiar physiognomy of the rounded bluffs when composed of rocks of volcanic origin, or of the vertical shore bluffs deeply grooved and streaked with red earth, or eroded into domes or conical hills when composed of elevated coralliferous limestone.

The reefs which encircle Mbengha, Komo, and Budd Reef, indicate approximately the land area once probably occupied by those islands. The islands must have been of considerably greater height; they have been reduced by denudation, and their area has been further diminished by extensive submarine erosion wearing away the ridges and spurs of the volcanic islands, and leaving submarine platforms of varying width, — dependent upon the nature of the material to be eroded, and the height of the land to be cut down, — upon the surface and outer edge of which corals established themselves. In the case of Komo and of Budd Reef, the islets which remain show the extent of the denudation and erosion. In the case of Mbengha the larger islands probably retain more of the character of the island which once covered Mbengha, representing its higher peaks, while the islets and rocks are all that remain of its lower ridges and slopes.

Olorua.

On our way into Komo we saw in the distance Olorua (Plate **22**), a small island with a ridge having three prominent humps, probably of elevated limestone, rising to a height of 250 feet. The island is surrounded by a fringing reef extending to a point for more than a mile off the south face. A small lagoon full of heads separates the north shore of the island from the narrow outer reef flat. We also passed the atoll of Thakau Vuite (Plate **22**), separated from Komo by a channel of about one and a half miles in width, with a probable depth of about 150 fathoms. The lagoon is about two miles and three quarters long by two miles broad, with a greatest depth of sixteen fathoms; there is an opening for boats into the lagoon on the northwest side. The encircling reef flat is narrow, and there is a sand key on the northeast horn of the lagoon.

OLORUA.

Totoya.

Plates 19^{a}, Figs 4-7, and Plates 23, 66-69.

Before entering the western passage through the outer reef surrounding Totoya, we steamed round the eastern and northern edges of the outer reef to obtain a good idea of this interesting island. Totoya (Plate **23**) is triangular in shape, enclosing an inner basin, nearly circular, of three miles in diameter, and with a greatest depth of 35 fathoms. The width of the rim varies from two miles to a low narrow isthmus on the western face (Plate **66**), the highest points of the rim being 1,200 feet above sea level. The eastern part of the rim is the broadest and highest. The basin is open to the south (Plate **67**), the horns of the rim being about two miles distant. Stretching across this opening is the extension of the outer reef, which connects at the extremities of the rim with the narrow fringing reef bordering the island. Between the edge of the fringing reef on the western horn and the outer reef there is a narrow but deep passage called the "Gullet" (25 fathoms), affording a good entrance into the basin filling the extinct crater of Totoya, in which we anchored close to the inner edge of the northern part of the rim. The outer reef extends unbroken from the entrance on the west side to its

BASIN OF TOTOYA CRATER, FROM THE SUMMIT OF THE NORTHERN RIM.

northeastern extremity; it follows irregularly the outline of the shore at a distance varying from one to over two miles. The outer reef off the north coast is broken into distant patches, leaving broad passages between them. North of the western passage the reef is also interrupted, leaving a boat passage. The outer reef flats are irregularly trapezoidal in outline, and quite narrow. The greatest depth in the outer lagoon is 27 fathoms. The eastern arm, and also the northern horn of the lagoon and the inner edge of the southern face of the outer reef, are studded with rocks and coral patches. The corals on the reef flats are thriving, and those on the patches inside of the lagoon are everywhere most flourishing. Many of the patches close to the outer shore line are in the extension of lateral spurs which have been eroded from the ridge of the rim. The general depth of the outer lagoon is over 20 fathoms along its central channel. Similar spurs run into the inner basin, and have formed extensive spits on which corals flourish, or islets and islands such as those figured on Plate 69, near the inner edge of the northern rim of Totoya. Near the centre of the basin there is an extensive coral patch, Kini Kini (Plate 23), formed upon the sides of a small islet rising from the bottom of the crater, as is so often the case in the craters of other volcanoes (see Plate 71). The volcanic rocks forming its centre are exposed at low water. The outer rim of the crater of Totoya has a diameter of six miles; it slopes quite evenly from the crest of the ridge to the outer and inner shore line; the slopes are cut by comparatively shallow valleys, separated by ridges with rounded crests. (Plates 67, 69.)

The water which pours into the inner basin over the barrier stretching across the horns of the crater finds its only outlet through the "Gullet," where it rushes through with considerable velocity. The scouring effect of the waters rushing out of lagoons has been noticed by all who have navigated among coral reefs, and the strong currents flowing out of the lagoons through the encircling reefs of openings are constantly referred to in the sailing directions.

In the extension of the western horn of the crater on the west of the "Gullet," are two small islets (Plate 68), the remnants of a part of the southern rim of the crater. Small islets also exist off the west coast, on the northern side of the isthmus. They are remnants of one of the spurs putting out from the west side of the outer rim. From what we have seen in Totoya, there is little doubt that the fringing reefs, the shore flats, the coral patches, and in different parts of the lagoon the outer reef flats are the remants of flats formed by the denudation and submarine erosion from the former extension of the slopes of the rim or of its spurs. These have been more or less connected together by the subsequent growth of the corals which have found a footing upon them. Kini Kini and the other islets about Totoya, as well as the negro-heads on the reef flats and patches, all show the volcanic substructure upon which has grown and is thriving now a thin crust of corals.

TOTOYA FROM THE NORTHEAST, DISTANT FIVE MILES.

It has been difficult to explain the great depth in some of the lagoons of some atolls (60 fathoms). It seems to me that the conditions occurring in an island like Totoya give us a simple explanation of what such depths mean in coral districts situated in volcanic regions. Provided that we assume that these lagoons are in a region of elevation, as are the Fiji Islands, and that its volcanic peaks or ridges and volcanoes have been denuded and eroded, and that nothing has been left to indicate their former existence beyond the reef flats upon which the corals of the present day are growing. Remembering also that the corals can form but an insignificant crust upon the slopes and flats which have been prepared for their growth by the processes of elevation and of subsequent erosion and denudation, and that the features characteristic of the existing state of things was not brought about by the growth of the coral reefs of to-day except in a very secondary manner. We are not discussing the question of the formation of great limestone banks by subsidence to attain the proper depth at which corals may begin to grow. We are only trying to give an explanation of the conditions which must have preceded and have led to the existing state of things.

The deepest water in the crater basin of Totoya is thirty-five fathoms, and it certainly cannot be held that a lagoon of such a depth has been formed by subsidence after the coral reefs have begun to grow. Let us now follow what would have become of Totoya had the denudation and submarine erosion which have brought it to its present state been continued during a longer period of time. A very few fathoms more, and we should have the rim divided into three large islands, — an eastern island with a ridge having a height of about 1,100 feet, a western island with a height of about 800 feet, and a northwestern island with a summit of the same height. These islands might thus be reduced to three separate ridges, giving no indication that they had formed part of the rim of the crater of an extinct volcano.

The denudation and erosion could be carried still further, leaving only islets, the summits of the higher peaks, to indicate the former position of the rim, the islets being joined by coral patches connecting their extremities, much as the present opening between the horns of the rim of the crater is closed by the outer reef. We may still further imagine it to be so far cut down as to form reef flats upon which coral would grow, thus forming a nearly circular atoll with a depth of 35 fathoms, — an atoll with the formation of which subsidence has had nothing to do. But this is not an imaginary atoll I am reconstructing. A number of such atolls are found in Fiji, the formation of which can be satisfactorily explained on the theory that the ring of coral patches represents the rim of an extinct volcano which has been cut away to below low water mark. Such atolls in the Fijis are probably Thakau Momo, Thakau Lasemarawa, Thakau Lekaleka, Motua Levu, Motua lai lai, Pitman and Williamson Reefs, and perhaps others.

The example of Thombia, one of the Ringgold Islands, in which there is only a distant outer reef, would also indicate the possibility of the rim of the crater of a small volcanic peak cut down to the surface and forming the circular flats upon which corals might grow. In the case of Thombia such a condition would result in forming a diminutive atoll not more than a third of a mile in diameter, enclosed within an encircling barrier reef.

We might also consider the "Boilers," the diminutive "Serpuline atolls" inside of the lagoon of the outer reef off the south shore of the main island of the Bermudas,[1] as a series of such interior atolls, though the mode of origin is very different from that of subordinate atolls, formed, as I have suggested, upon the rim of an extinct crater like Thombia. In either case, the explanation of the formation of such interior or subordinate atolls is radically different from that given by Darwin[2] for their growth in the Maldive atolls, an explanation also accepted by Dana.

It is becoming more and more apparent that each locality must be

[1] Bull. Mus. Comp. Zoöl., XXVI. No. 2, 1895, Plates XXII.–XXVI., p. 253.

[2] Darwin's Coral Reefs, 3d ed., p. 44.

considered by itself, and that no sweeping generalization can take in the formation of all coral reefs. Such atolls as those of Alacran on the Yucatan Bank of the Hogsty Reef in the Bahamas owe their origin — I mean the conditions existing there now — to entirely different causes from those which have brought about the formation of some of the atolls of Fiji, and the atolls of Alacran and of Hogsty themselves again owe their origin to different causes. The barrier reef of Florida does not owe its origin to the same causes as those which have led to the formation of the Great Barrier Reef of Australia, or the barrier and fringing reef surrounding parts of Viti Levu, or some of the other islands of the Fiji group.

It is playing with words to call such atolls as I have mentioned above pseudo atolls, as is becoming the fashion, and to speak of the localities to which Darwin's theory of the formation of barrier reefs and of atolls does not apply as exceptions to the rule. These exceptions now cover a good deal of ground. They include nearly all the coral reefs which have been examined by recent investigators, — from Semper in the Pelew Islands, Rein in the Bermudas, Murray in Tahiti and elsewhere, of Forbes, and of Bourne, of Guppy in the Solomon Islands, Krämer in Samoa, and others, — down to my own in Florida, the Yucatan Bank, Cuba, Bermuda, the Bahamas, and the West India Islands, as well as in the Galapagos and Sandwich Islands, besides the exploration of the Great Barrier Reef of Australia, and of the Fiji Islands. Surely the list of investigators and of localities is long enough. The negative evidence is now becoming overwhelming, and the recent borings at Funafuti have not weakened the position of those who do not recognize the Darwinian theory as of universal application, and as not having been proved to exist in a single instance, either by a careful examination of the locality or by borings.

Taviuni.

Plates 4, 18, 60.

The islands of Taviuni (Plates **4**, **18**) and of Kandavu (Plates **10**, **11**) illustrate admirably the formation of reefs encircling denuded and eroded extremities of large islands, and readily explain the existence of very irregularly shaped reefs representing the former outline of the islands which they replace. Other characteristic points similar in their origin are the great spits forming the Namena Barrier Reef, which connects with the extensive reef platforms reaching towards Ovalau from the southeastern extremity of Vanua Levu (Plates **3**, **3^{a}**) and the northeastern spit of Vanua Levu, which breaks up into Kioa and Rambe Islands and the reef-bound platform from which they rise (Plate 4).

On the platform of submarine denudation and erosion Namena and Vatu i thake Islands, as well as a few isolated rocks on the western edge of the southeastern horn of the Vanua Levu Barrier Reef are the only remnants of the former southern extension of Vanua Levu. To the southeast of this must have existed a dumbbell-shaped island of considerable height, of which only the summits of Makongai and of Wakaya are left (Plate 3ª).

The island of Taviuni is, with the exception of the shore fringing the northern half of the island and of the point of reefs off Vuna Point, destitute of reefs. The island is about 23 miles long, from five to eight broad, sloping uniformly to the shores from the backbone of the island. This rises to a height of over 4,000 feet. The main ridge sends off a few spurs towards the northeastern face of the island. The fringing reef attains its greatest width to the east of Naiselesele Point. It encloses a few small volcanic islets, varying in height from 60 to 90 feet, and the somewhat larger island of Mbuimbani (Plate 60), lying to the south, and which rises to a height of more than 400 feet. To the south the fringing reef becomes again quite narrow, and disappears at Laveine Point.

Immediately north of Somo Somo Strait the submarine platform widens. Koro Levu Islet and Phillips and McPherson Rocks are included within shallow soundings covered with reef patches running out from the west shore of Taviuni. At a somewhat greater distance from the west shore of Taviuni within the 50 fathom line are Champion, Breaknot, and Maté Rocks, and to the northeast of Naiselesele Point the submarine platform reaches its greatest width, the Gangway Rocks and the bank connected with them being the most distant of the outliers of Taviuni.

To the eastward of Taviuni lie the islands of Ngamia, Lauthala, and Matangi, separated from Taviuni by the Tasman Strait. The plateau from which these islands rise is really the extension of the shoal lying to the east of Taviuni and the outer reef which extends from Matangi east of Lauthala and south of Ngamia, stretching across Tasman Strait in disconnected patches and joining the fringing reef off Thurston Point. To the westward of Matangi the outer reef extends only in broken patches, and is seen also in the many disconnected patches found in the western part of Tasman Strait. Between Matangi and the northeastern horn of the outer reef there are two passages across it. The lagoon enclosing Ngamia and Lauthala has a greatest depth of forty fathoms and an average depth of over twenty, except to the east of Lauthala, where the outer reef joins the fringing reef which skirts Lauthala and Ngamia. There are a number of coral patches all through the lagoon, but they are most abundant along the inner edge of the southern line of the outer reef.

Ngamia and Lauthala are both volcanic; the former rises to a height of 1,000 feet. Both are indented with deep bays.

Along the shore of Thurston Point we found a conglomerate in course of formation, composed of rounded pebbles of lava cemented together with broken fragments of coral.

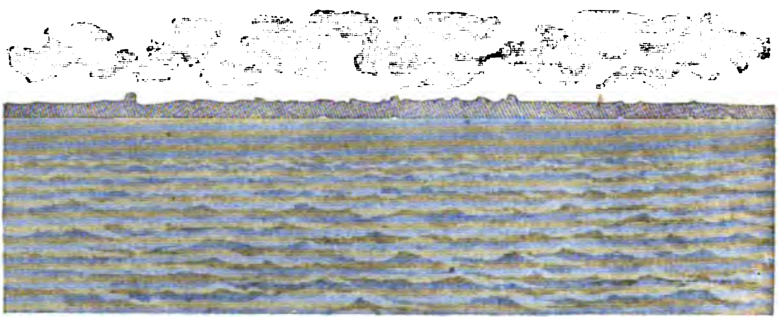
ELEVATED ISLANDS COMPOSED OF CORALLIFEROUS LIMESTONES.

Ngele Levu.

Plates 17, 17^a, Figs. 5-12, and Plates 95-99.

Ngele Levu is an elongated pear-shaped atoll, somewhat constricted at a few points (Plate **17**). Its length is fourteen miles and its greatest breadth seven. The lagoon is enclosed by a continuous outer reef, varying in width from a quarter of a mile to over a mile. The western face of the outer reef is broken into patches leaving excellent deep passages for ships. The depth in the lagoon is quite uniform, the bottom being very level, varying in depth from about five to nine fathoms at the eastern extremity, and sloping very gradually to fifteen or sixteen at the western entrance. The bottom is composed of coralline algæ, broken shells, and coral sand, as well as masses of dead corals derived from the disintegration of the former elevated coralliferous limestone which once covered the whole area of the lagoon. The lagoon is free from coral patches except at the eastern end, which is studded with heads of old coral and patches of living coral. These heads also form a belt of considerable width along the inner side of the outer reef flats.

The reef flats are made up of elevated coralliferous rock which has been planed off to the level of the sea, and scooped out below it to form the lagoon. At the southern of the western entrances there is a small sand key, and at the northeast end there are three islands, Ngele Levu, Tai ni Mbeka (Plate **96**), and Taulalia (Plate **95**). The outer faces of these islands form the sea face of the outer reef, there being no outside reef flats. These islands are entirely composed of elevated coralliferous limestones, rising on Ngele Levu to about sixty feet, on Tai ni Mbeka to forty feet, and on Taulalia to thirty feet. The process of disintegration which has taken place can still be seen going on at the extremities of the island of Ngele Levu. On the reef flat near it, as well as along the inner beach, crop out many negro-heads of elevated limestone rock, and between the smaller islands, which are now only connected by a reef flat, the islands themselves being undercut and their



TAULALIA, NGELE LEVU LAGOON.

surface deeply pitted and honeycombed (Plates 95, 96). On Taulalia many large domes of harder material, somewhat conical, still exist, which have not been rounded off to the general level of the island.

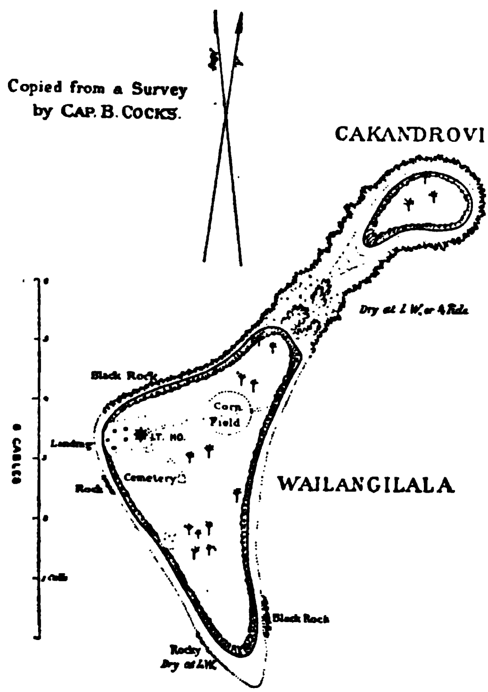
We walked a good part of the length of the island of Ngele Levu, and crossed it at right angles. The elevated tertiary limestome rock was found cropping out at all points (Plate 97), and towards the north-eastern shore we came upon a belt of limestone nearly devoid of vegetation, which must have risen at points to fully sixty feet above the shore line. The surface of that part of the island was full of deep potholes and crevasses of all sizes and shapes, separated by ridges and columnar or conical masses, some of them fully fifteen feet alove the general level of the surrounding area (Plate 98). The rock surface in all directions was pitted and honeycombed, and eroded into thousands of sharp points and needles, the aspect of this island recalling a similar structure so common among the Bahamas. At Observatory Point, the southern extremity of the island, this very characteristic structure is quite well marked, and shows admirably the gradual passage of an island composed of elevated limestone rock into a reef flat identical in all respects with the reef flats surrounding the lagoon. Plate 99 shows the characteristic shore vegetation along the narrow cultivated strip of the island, while Plates 97 and 98 show the inland vegetation.

We found rather distant coral patches growing in the lagoon in from six to seven fathoms of water, close up to the inner edge of the outer reef, starting from an underlying base of tertiary limestones, fragments of which we brought up with the dredge. And upon the plane of the outer rim of the lagoon, composed of the same tertiary limestones, corals were growing to a depth of from six to ten fathoms, or more perhaps.

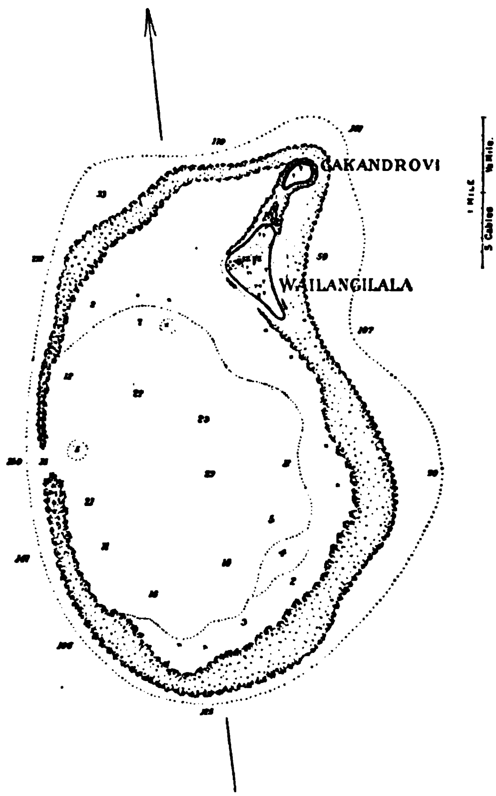
Wailangilala.

Plates 18, 109, 110.

The island of Wailangilala is somewhat triangular, and connected by a spit of coral beach rock with the small island of Cakaudrovi to



the northeast. The east side of the larger island is about fifteen feet above high water mark. Both islands are low, with sandy or beach rock beaches, and covered with cocoanut trees and shrubs (Plate **110**). The islands are in the northeast angle of a nearly elliptical lagoon (Plate **18**), surrounded by a reef flat varying from a quarter of a mile to more than



a mile in width. The outer reef is about nine miles in circumference. There is an entrance for ships into the lagoon in the western reef flats.

The depth of the central part of the lagoon is from 22 to 23 fathoms, and the bottom is mainly coralline and coral sand, with broken shells. The inner edge of the reef flat is flanked by a broad belt of coral patches, which extend upon the flat itself, with here and there an isolated patch in six or seven fathoms of water.

Wailangilala was selected, after consultation with inhabitants of the Fijis well acquainted with the group, as affording an isolated atoll with a steep submarine slope, and an island on the outer rim on which to establish the boring plant. Having a lighthouse on it, with a keeper and assistants, it afforded unusual facilities for establishing a comfortable camp for the boring crew, who were at work a couple of days after landing.

The following is the record of our boring at Wailangilala.[1]

From the surface —

To 20 feet, coral and coralline sand with broken shells, like that on the beach.

20–30 feet,	coralline sand.						
30–40 "	coral and coralline sand, coarse.						
40–50 "	fine coralline sand.						
49–51 "	parts of core of yellow limestone (elev. limestone).						
51–61 "	"	"	"	"	"	"	"
61–71 "	"	"	"	"	"	"	"
71–80 "	"	"	"	"	"	"	"
80–85 "	"	"	"	"	"	"	"

It was on the western inner edge of the island (Plate **109**) that I established our boring apparatus, soon after arriving at Suva, and while under the impression conveyed by the newspapers, and from published reports, that the second Funafuti boring expedition had demonstrated that at the Funafuti atoll true coral reefs extended to a depth of 643 feet. This information seemed so positive that had it been received before the shipping of my outfit to Fiji via Australia, I should have remained at home, convinced that at any rate, whatever had been my experience in the West Indies, Australia, and the Sandwich Island reefs, yet that in a region of typical atolls in the Pacific the conditions of subsidence suggested by Darwin and Dana might exist, unless the boring at Funafuti proved eventually, on closer examination, to have been carried on in the sea face talus of a reef. But my outfit having left, I was not prepared to accept the preliminary conclusions of Professor David as recorded by the papers, and I started on my expedition ready to confirm by my own borings the truth of the great thickness of modern coral reefs in atolls of the Pacific, or to give some other explanation of this apparently overwhelming proof of the correctness of Darwin's theory.

From what we saw of the elevated coralliferous limestone at Ngele Levu, Vanua Mbalavu, Mango, and other points in Lau on our way to Ongea, it was very evident that these limestones attained a great thick-

[1] The bore hole was about five feet above high water mark, and about thirty feet from the shore line, a few feet north of the Landing (figure on page 45).

ness, — 800 feet at Tuvuthá, 1,000 feet at Vatu Vara. Therefore as soon as the drill struck the limestones it might correspond to any height in the beds exposed elsewhere, beds which at Mango, Kambara, and Vanua Mbalavu we had observed to rest upon a volcanic substratum. It was natural that immediately on my return to Suva after our first trip round the Eastern Archipelago I should send to Wailangilala orders to stop further boring, and to bring the crew and machinery back to Suva. For it seemed a waste of both time and money to bore and obtain a core from an indefinite datum plane, when the same evidence could be obtained by the examination of any one of the bluffs of elevated coralliferous limestones with which we had become familiar in our first trip. But, unfortunately, we were not equipped to make a thorough exploration of such a section, not being provided with explosives or drills, and had to content ourselves with somewhat fragmentary collections at the more accessible points. However, this is a subject which I hope to attack again under more favorable conditions.

The boring at Wailangilala shows that the island is the fragment of an ancient island of larger size, which once covered the whole area of the lagoon. Being at the northern extremity of the atoll, it was less subject to the destructive agency of the sea due to the prevailing southeasterly winds, and thus there was left a wider reef flat, the last to be worn away by the action of the sea. It also shows that at a depth of forty feet we meet the underlying elevated limestone forming the substratum of the northern reef flat of the lagoon. As will be noticed from the Figure on page 46, the western reef flat is much narrower than the eastern and less exposed face of the lagoon.

The boring at Wailangilala is from the remains of an upheaved coral island, as has been suggested by Gardiner;[1] but it is also the remnant of an island which once occupied the whole of that part of the atoll. Aiwa shows a stage antecedent to that of Wailangilala, the island on the rim of the lagoon being still of considerable height. Many of the reef rocks (negro-heads), which Gardiner considers as having been thrown up by hurricanes, are the remnants of the elevated reef rock outliers left from the denudation of the flats on which they occur, and which once rose to a greater height but have gradually been eroded and planed down to their present elevation.

But Gardiner is wrong in assuming that the islands of the atolls are converted into land. Such is by no means necessarily the case. The islands on the rim of an atoll, as Ngele Levu, consist of elevated coral-

[1] *Loc. cit.*, p. 445.

liferous limestone rock, and are the remnants of the former land mass once covering the area of the atoll of Ngele Levu.

Nuku Mbasanga.

Plates 18, 22ª, Fig. 18, and Plate 108.

We skirted along a part of the southwestern edge of Nuku Mbasanga atoll (Plate 18). The atoll is oblong, a little over two miles long, open to the northwest, where the reef flats are broken up into numerous coral heads. Within the broad reef flats are a small sandy cay, Nuku Mbalate on the western face of the atoll, and the islet of Nuku Mbasanga (Plate 108), the shores of which are covered with coral beach rock, or patches of elevated reef rock, judging from the character of the negroheads which crop out on the western side. Both the islands are covered with coacoanuts and shrubs.

There is every reason to believe that the islands of the Nuku Mbasanga group are the remnants of an island composed of elevated limestone, which has been denuded and eroded to its present condition, and partly covered, as Wailangilala has been, with coral sand.

Nukusemanu and Nanuku Reefs.

Plates 18, 103–107.

To the eastward of Budd Reef, and separated from it by a channel about nine miles wide, is situated an elongated, angular, irregularly shaped atoll, terminating at its southern extremity in a long ridge of reef flats called the Nanuku Reef. These send out spurs, the extension of which connects with the Nukusemanu Reef and encloses a lagoon fully twenty-four miles long and from two to six miles broad. The greater part of the eastern face of the reef is not awash, being made up of a long series of coral reef patches, with from one to six fathoms of water, with deeper water between it and the extension of the Nanuku Reef. A tongue of the ocean runs westward from 118 fathoms in the gap separating the extremities of the reefs, rising to a ridge with five to ten fathoms, separating it from a deep pool with as much as forty-six fathoms near the eastern face of the central part of the western reef flat of Nanuku Reef. Only an occasional reef patch rises to the surface on that face. On the northeast horn is situated Nukusemanu Island, a small sand key covered with cocoanuts. On the northwest face the Nukusemanu Reef flats are seen to be well covered with flourishing coral patches, but nearly the whole of the west face until it joins the western spur of Nanuku Reef consists, like the east face, of a long but narrow reef flat, with from two to seven fathoms, and studded with heads. The greatest depth in the lagoon is 52 fathoms, with an average depth of from 25 to 40 fathoms. The interior of the lagoon, especially the northern part, is studded with heads.

We examined the islets on the southern spits of the Nanuku Reef. The northern islet, Nanuku lai lai, has been nearly washed away during the hurricane of 1893 (Plate **107**). The southern islet is covered with shrubs and cocoanuts (Plate **104**). The eastern face of this islet, Nanuku Levu, is flanked with beach rock (Plate **106**). There were a large number of negro-heads of beach rock and of elevated coralliferous rock scattered upon the reef flats adjoining the island (Plate **103**), and both to the north and towards the southern extremity of the reef flat ridge (Plate **105**). Coral heads begin at about seventeen fathoms off the lee side of the reef, the patches increase in size and number at twelve fathoms, and form a very fine flourishing belt between six to one and a half or two fathoms. We could trace these coral patches on the narrow reef flat ridge extending northward. This ridge is at some points so narrow that the breakers form a long white mass of rollers as they fall from the windward to the leeward side of the reef flat. The leeward pitch is not as steep as the charts seem to indicate. We found a hundred fathoms on that side, hard bottom, at a distance of one and three quarters miles from the leeward edge of the reef flat, two and a quarter miles northerly from Nanuku lai lai (Plate **18**).

The island which once covered the tract extending from the northernmost horn of the Nukusemanu Reefs to the southwestern horn of the Nanuku Reefs (Plate **18**) was probably flanked by outer ridges of hills running into a long narrow ridge at the southern extremity, of which Nanuku lai lai and Nanuku Levu islets are the solitary remnants, while Nukusemanu Island is the only fragment of the northern extremity of the eastern ridge. There must have been a valley separating the ridges now indicated by the open lagoon, with a greatest depth of over forty-five fathoms, extending from Nanuku Reef to Nukusemanu, Reef, which was cut into at many points all along the outer edges of the ridges, and connected the plateau of submarine erosion with the great sound of the interior.

Tuvuthá.

Plates 20, 88, 89.

Tuvuthá Island is triangular in shape; its northern face is about one and three quarters miles long; the island is nearly three and a half miles long, and trends in a northwesterly direction from the southern point to the northern face (Plate **20**). It is surrounded by a barrier reef. The greatest width of the enclosed lagoon is about three quarters of a mile on the eastern side; it is somewhat narrower off the western face of the island. At two points on the northern side of the island the outer reef becomes a fringing reef for a short distance. There are a couple of boat passages into the lagoon through the outer reef flats, one on each side. The lagoon varies in depth from two to nine fathoms. With the exception of the central part of the eastern lagoon, it is studded with coral patches and negro-heads. The latter are especially numerous off the northern face of the island between those points where the outer reef becomes a fringing reef, and empounds a small distinct lagoon.

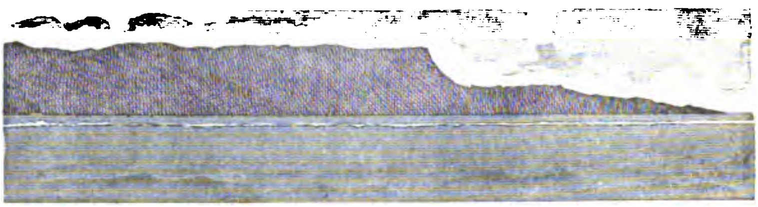
The central ridge, occupying the interior of the northern part of the island, runs parallel to the west coast, and as far as I could judge consists of coralliferous limestone elevated to a height of eight hundred feet. The central ridge is surrounded by a more or less continuous ridge, forming an outer rim and surrounding the inner depressed part of the island. This ridge consists entirely of elevated limestones, forming along the northern face a collar of steep bluffs (Plate **88**). Other parts of the ridge, especially on the west side of the island, have been greatly denuded and eroded into rounded peaks and domes, while the southeast point is marked for its steep bluffs and sharp ridges (Plate **89**). Where the bluffs rise from the shore of the lagoon, they are deeply undercut. The outer ridge not being low and broken at any point, no interior lagoon or sound has been formed with the exception of a small bight on the southern part of the eastern face of the island (Plate **20**).

The central volcanic mass which has elevated Tuvuthá as well as Naiau has not broken through the elevated limestones, although it has assumed the appearance of the wide round rim of an extinct crater. But, as will be seen in the case of Naiau, the formation of the central basin is not due to volcanic agencies, but to atmospheric causes.

Naiau.

Plates 20, 22[a], Fig. 1.

Naiau Island is, like Tuvuthá, composed entirely of an elevated limestone ridge forming a continuous rim round a central depression stated to be about 200 feet lower than its highest points, which rise from 530 to 580 feet above the level of the sea. The sea face of the rim rises



NORTH POINT OF NAIAU.

in nearly perpendicular bluffs round the island. At their base they are deeply undercut, and the larger fragments are eroded into dome-like heads. Off the southeastern point an islet has been isolated from the island. Naiau is surrounded by a fringing reef broadest on the eastern face, about half a mile wide, where at half tide boats can pass between it and the shore, forming an incipient lagoon, and enter through a narrow boat harbor passage, out of which, I am informed by our pilot, runs a strong current. There are numerous negro-heads all along the outer edge of the fringing reef, especially near the northwestern point of the island, where the fringing reef is narrowest.

Naiau,[1] Tuvuthá, Kambara, Wangava, and other elevated islands, consisting of coralliferous limestone, have been considered to be elevated

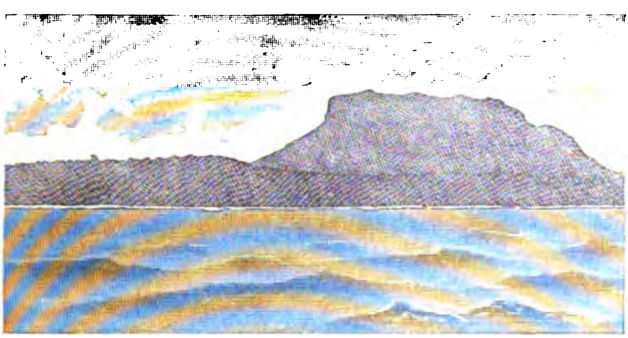
NAIAU, SEEN FROM THE EAST.

atolls, owing to the existence of a depression in the summit, which is looked upon as representing the former lagoon. While that may be the

[1] Moore, Nature, March 18, 1897, p. 463. Others have looked upon these islands as extinct craters.

case, I am inclined to consider these central basins as due to the action of atmospheric agencies, and to look upon them as similar to the gigantic banana holes, as they are called, occurring in the Bahamas, which are undoubtedly due to the solvent action of the rains overcharged with carbonic acid, which carry off the limestones, and, percolating through the mass, leave the saucer-shaped basins characteristic of the so called elevated atolls. In such islands as Naiau, Vanua Vatu, Tuvuthá, Kambara, and Wangava, the central depression has not extended very far towards the sea level. But in such islands as Mango the central depression has formed a small lagoon, in Namuka submarine erosion has carried off one side of the rim; in Fulanga (Plate **22**) the process has been carried still further by the direct action of the sea and of submarine erosion, forming a large lagoon; and the conditions existing at Ongea, Yangasá, Aiwa, and finally at Reid Haven, Wailangilala, Ngele Levu, etc., illustrate the different stages in the transformation by submarine erosion of a so called elevated atoll of tertiary age into an atoll of the present epoch.

The probable extent to which atmospheric agencies have contributed to shape such central basins is also shown from the presence of extensive caves in the elevated limestone islands of Vatu Leile, of Thithia, and of Ngillangillah, and in the numerous cracks, caverns, and cavities which characterize the faces of the vertical bluffs of elevated limestone wherever we have met them in the Fijis (see Plates **74**, **77**, **92**).



VATU VARA, SEEN FROM THE EAST.

Vatu Vara.

Plate 19.

On the last trip of the "Yaralla" from Suva to Wailangilala, Captain Thomson examined for me the islands of Vatu Vara, Yathata, Kaimbo, and Naitamba. The accompanying account is based upon his notes.

Vatu Vara or Hat Island (Plate **19**) is one mile and a quarter in diameter. Its summit is flat, and falls off on all sides in steep cliffs. It attains an altitude of 1,030 feet. The cliffs consist of elevated limestone standing out conspicuously through the dark foliage which covers the island from base to summit. Up to the very summit of the island the exposed rocks are seen to consist of limestone. The island is surrounded by a fringing reef nearly a mile in width on the west coast. On the east and north sides the sea breaks against the nearly vertical limestone cliffs. They are deeply undercut. On the northwest side two separate masses of limestone stand out midway between the base of the cliffs and the outer edge of the reef. An incipient lagoon, open to the north, is forming along a part of the west coast of the island.

Yathata and Kaimbo.

Plate 19.

The islands of Yathata and Kaimbo (Plate **19**), which rise respectively to the height of 840 and 150 feet, are composed of elevated limestone rock. A fringing reef encloses them both. It attains a width of over half a mile where it connects the islands, and is nearly a mile wide off the north of Yathata. Off that shore a number of small islets and heads stand out between the island and the outer edge of the reef. Elsewhere the fringing reef is narrow. Between the islands in the middle of the fringing reef stands out the islet of Nuku Levu, 90 feet in height, and a few heads. There appears to have been a secondary elevation on the south side of Kaimbo, where the undercut ledge has been raised about twenty feet above high water mark.

I am informed by Captain R. Cocks that Katavanga is composed of elevated limestones.

Aiwa.

Plates 21, 22ª, Figs. 13-15.

Aiwa consists of two small elongated islands, the western one of which is not quite a mile in length (Plate **21**). Both are composed of elevated limestone, pitted and honeycombed, forming low vertical bluffs along their southern faces. The highest points of the islands are respectively 210 and 200 feet. They are connected by a coral reef awash at low tide. The islands are in the middle of the southern face of the outer reef flat, which encloses an elongate narrow triangular lagoon nine miles in length. From the extremities of the islands off the south face projects a horn of the outer reef, forming a small enclosed lagoon separated from the principal lagoon and with a greatest depth of ten fathoms. The greatest depth of the principal lagoon is 23 fathoms. The northern face of the outer reef is much broken, and flanked by large patches of corals and heads, with a wide entrance into the northwestern end of the lagoon. The western face of the lagoon is three miles long. The inner edge of the western face is flanked by a broad belt of coral patches and heads. The coral patches are growing upon sunken heads of elevated reef rock, the remnants of the elevated reef once covering the area now occupied by the Aiwa lagoon. The reef flats consisted wherever we saw them of elevated reef rock planed off to a general level, upon which coral patches were growing.

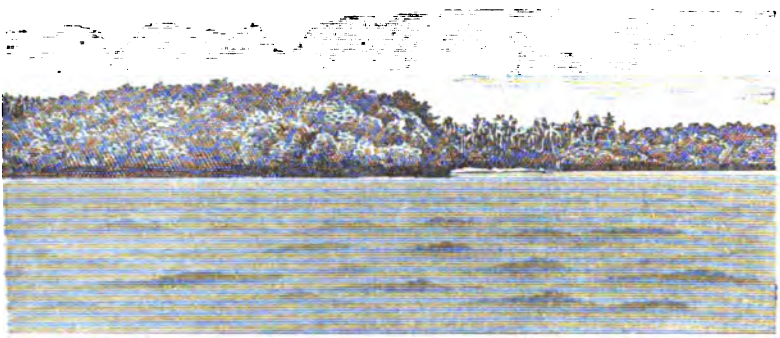
This group is historically interesting, as Dana in his Corals and Coral Islands (p. 264) gives a section across the islands and lagoon, which according to him illustrates very forcibly the effect of subsidence in the formation of atolls. A more unfortunate selection could not have been made. But Dana did not visit this group, and took his information from the charts, or he would not have chosen as an illustration an island group which consists of elevated limestone rock, — islands which after their elevation have suffered most extensive denudation and erosion, and upon the outer edge of the surrounding platform the corals of the present epoch have found a footing and formed a sheet of very moderate thickness. The lagoon between the encircling reef and the islands has been hollowed out by mechanical causes similar to those which I have alluded to elsewhere, and which have in my opinion shaped the lagoons of all the atolls and barrier reefs of the Fijis.

Dana assumes the lagoon of Aiwa to have been formed during the slow subsidence of the island enclosed within its reef, while there is every evidence that the lagoon of Aiwa has been scooped out by submarine erosion, and the island, consisting of late tertiary limestones, has been lowered by denudation, and that the limestones after their elevation have remained at the present level, and that the corals now growing upon the outer rim and upon the reef flats, as well as the coral heads inside of the lagoon, have but little thickness, and that well within the greatest depth at which reef-building corals can grow.

Oneata.

Plates 21, 22[a], Figs. 10-12.

Oneata Island is a low ridge of elevated limestone, rising to a height of 160 feet, connected at its eastern extremity by a coral reef with the islet of Loa, of similar structure to Oneata, and rising to a height of 140 feet. Towards the eastern extremity of Oneata, on the northern side, the island is indented by deep bays, studded with mushroom-shaped islets and large heads barely cropping to the surface. The spit



ONEATA.

protecting the bay from the east rises vertically, is deeply pitted, full of potholes, and honeycombed and perforated by a large opening similar to the Hole in the Wall at Abaco in the Bahamas. Everywhere on the surface of the island we found the elevated limestone cropping out. The southern face of the island is also indented with bays, the beginning of shallow sounds which are now cutting Oneata into smaller islands by undermining the shore line and forming low vertical cliffs, probably by the same processes which disintegrated the area formerly occupied by the elevated limestones, and of which Oneata and Loa are the remnants.

ISLET OFF ONEATA SHORE.

Oneata lies about a mile from the inner edge of the outer reef flat, enclosing a triangularly shaped lagoon, with a greatest depth of 21 fathoms. The length of the southern reef flat is a little over ten miles, that of the northern face about nine miles, and that of the western and northwestern faces connecting them is five miles. There are three passages on the western and northwestern faces, and one through the northern face. The bottom of the lagoon, between the reef patches and heads, is covered with coralline algæ and with coral sand. There are many large heads scattered along the inner edge of the northern reef flat, and on the extension of the western extremity of the island.

Namuka.

Plate 22.

We did not visit Namuka, but steamed near enough to the island to recognize its distinctive features. It is a narrow, undulating ridge, four miles long, rising to a height of 240 feet; it is composed of elevated limestone. On the southern and western faces there are deep bays, or incipient sounds, which, if extended, would divide the island into a number of islets. The island is surrounded by a fringing reef off the southwestern extremity, and off the eastern point of the island. Between these points an outer reef extends off the south coast, forming a narrow and shallow lagoon full of heads, with five fathoms at its deepest point. On the northern face the western part of the lagoon is deeper, having thirteen fathoms. The horns of the outer reef of the northern and western faces are connected by broken patches and heads which form the harbor of Namuka.

About three and a half miles northeast from the entrance to Namuka Harbor lies Wilkes Reef (Plate **22**), a flat a little over half a mile in length, dry at low water, with outlying rocks and banks within the surrounding 100 fathom line.

Yangasá.

Plates 22, 22[a], Figs. 8, 9, and Plates 90–93.

The cluster of Yangasá (Plate **22**) consists of four islands and numerous rocks and islets, all of which are composed of elevated limestone. The largest island of the group, Yangasá Levu, is nearly two miles in length and about half a mile wide. Its shores are formed of precipitous cliffs, which surround the whole island; they are deeply undercut at the base, perhaps more than any other island we have seen in Fiji. The crest of the highest ridge is flat, and runs at a general level of about 300 feet. The highest summit, toward the southern end of the island, is nearly 400 feet; off that point there are indications of a terrace at about one third the height of the island, as if the elevation of this group had taken place at two successive periods. Yangasá Levu seen from the west, on the way to Ongea, appears hat-shaped, with a high terrace forming the rim. The island of Yangasá Levu is from one to two miles distant from the inner edge of the outer reef flat forming the eastern horn of the lagoon. Along the western side of the lagoon are

YANGASÁ LEVU.

situated Navutuira, in the northwest angle of the lagoon, which rises to 270 feet; this is connected with the islet of Yuvutha (Plate **90**) by a long narrow reef studded with mushroom-shaped rocks rising above high water mark. The whole of the northwestern part of the lagoon to the west of the ship passage on the north face of the outer reef flat is also thickly studded with negro-heads and with mushroom-shaped rocks of all sizes and shapes, which cover the wide reef flat to the west and north of Navutuira. The large mushroom-shaped heads are generally on the extension of spits or headlands of the two islands named.

The crest of Navutuira is undulating, and from its shores rise low undercut vertical bluffs. Yuvutha (Plate **90**), on the contrary, has a conical outline, its highest summit rising to 240 feet; its vertical shore bluffs are higher than those of Navutuira, deeply undercut; they are nothing but the rim of a sound left from the disintegration, denudation, and erosion of the adjoining land. Such rims are at a distance readily mistaken for the rims of extinct craters. We anchored off the west side of Navutuiloma, the most southern of the islands along the west side of the lagoon. The small bay on the north face of Navutuiloma resembles closely a part of the rim of an extinct crater. But that rim and those forming the eastern and western points are entirely composed of elevated limestone, full of caverns and caves, pits and potholes, many of them full of red earth, as is the case wherever elevated limestone is met with; it is deeply honeycombed and cut into ridges (Plate **92**), upon the edges of which rise endless sharp pinnacles and needles. This was also the structure and appearance of the inland slope of the island where we landed.

The little bay was studded with mushroom-shaped and conical islets and rocks, all deeply undercut (Plates **91**, **93**), and the bottom in from two to four fathoms was covered with sunken coral patches and heads rising at all depths.

Some of the islets were covered with bushes and cocoanut trees, like the main island. The highest point of Navutuiloma is 210 feet; it is a little over one mile in length, and is larger than Navutuira. The shape of the outer reef flats enclosing the lagoon of Yangasá (Plate **22**) is irregularly rectangular, with rounded angles; the faces are each about five miles long, the western face being the longer. On the eastern and northeastern side, the reef flat is quite narrow, but it is studded along the inner edge with a belt of heads and coral patches and negro-heads. Off the southeastern horn, the reef flat becomes very wide, projecting in a point fully two miles beyond its general line. The reef flats of the southern and western faces are also broad, fully a mile in width in some places, and at the northwestern horn the reef flat is more than a mile and a quarter wide.

On the northern face of the lagoon a tongue of deep water (145 fathoms) fully a mile wide runs towards the centre of the lagoon; this is the passage used for entering the lagoon. The slope of this part of the lagoon is very steep, and it is studded with coral patches and heads growing upon the remnants of the former island of Yangasá. This narrow and deep tongue of the ocean represents probably an original valley formed in the uplifting of the island, and has no connection with a subsidence of the island during the formation of the encircling reef, which has grown subsequently upon the platform of submarine erosion formed by the wearing away of the original land mass. The average depth of the northern part of the lagoon is from 14 to 19 fathoms. The southern part, between Yangasá Levu and Navutuiloma and the reef flat, is shallower, from six to twelve fathoms, with a still shallower belt along the inner edge of the southern reef flat.

Off the southeastern extremity of Navutuiloma extend a number of mushroom-shaped rocks and islets, deeply undercut and eroded into fantastic crests, pinnacles, and summits. The reef flat of the western face of the Yangasá lagoon is full of thriving coral patches, which extend along the inner edge, between and upon the negro-heads, down to seven or eight fathoms. The formation, by erosion and denudation, of diminutive or incipient sounds, as in the bay of Navutuiloma, is interesting as representing one stage in the action of such processes, of which others can be followed in the conditions which have been reached by such islands as Namuka, Mango, Ngele Levu, Fulanga, Oneata, Ongea, and others. It is quite probable that the islands and islets of this group represent the remnants of the submarine erosion and denudation which have cut the greater island of Yangasá, consisting of elevated limestone, which once occupied the area of the lagoon, into smaller islands by a process similar to that now going on to cut up the island of Navutuiloma, — a process which has left, as indicating its former greater extent, the islands of the cluster, its rocks and islets, and the numberless heads cropping out everywhere over the outer reef flats, and in the extension of the spits and points of its islands.

To the eastward of the Yangasá cluster, and separated from it by a narrow channel of about half a mile in width and a depth of a little over 100 fathoms, lies Thakau Levu (Plate **22**), an elongated horseshoe-shaped atoll, nearly four and a half miles in length, with a greatest breadth of less than two miles. The lagoon enclosed by the outer reef flat is open on the west face. The greatest depth in the lagoon is 11 fathoms; it is studded with heads and patches. The reef flat at the eastern point of the lagoon is fully a mile wide.

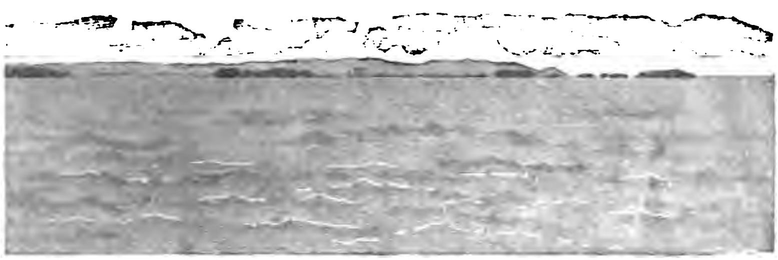
South of Thakau Levu (Plate **22**) lies the flat reef of Thakau Thikondua, and the small island Naiabo, of elevated limestone, rising to a height of forty feet, surrounded by a narrow encircling reef enclosing a shallow lagoon. Still farther south are the flat reefs of Thakau Reivareiva and Thakau Nasokesoke, both, according to the sailing directions, dry at low water and steep to all round. We did not visit either Thakau Levu or the last mentioned reefs.

Ongea.

Plates 22, 22[a], Figs. 6, 7, and Plate 94.

The Ongea group consists of two large islands, Ongea Levu and Ongea Ndriti, and numberless mushroom-shaped or conical or dome-shaped islets and rocks, studding both the passage between the two principal islands or fringing the shores or extending across the openings of the bays which indent the coast line of Ongea Levu and Ongea Ndriti (Plate **22**). The larger island, Ongea Levu, runs nearly north and south; it is four miles long, and varies from one to two miles in width; it rises to a height of 270 feet. This island lies in the centre of the northern part of the lagoon, about equidistant from the outer encircling reef flats, within a channel from three quarters of a mile to a mile in width, and varying in depth from seven to twelve fathoms. Off the southern end of Ongea Levu the lagoon expands, and attains a width of nearly six miles. The outer reef flat is narrow, but expands to a width of three quarters of a mile off the southern face of Ongea Ndriti, where it becomes a fringing reef. Ongea Ndriti is nearly two miles long and one mile broad, and rises to a height of 300 feet. The Barracouta Passage is the only ship channel leading into the lagoon. It opens through the western reef flat into the widest part of the pear-shaped lagoon, a little south of the extremity of Ongea Levu. The greatest length of the lagoon is about eight miles.

The Ongea Islands consist of elevated limestone, rising in nearly vertical cliffs along the shore line. This is deeply indented by broad and deep bays, forming small irregularly shaped sounds, which in the case of Ongea Levu have nearly cut that island into two (Plate **22**). The openings of the bays and the shores of the islands themselves on the western and



SOUTHWEST POINT OF ONGEA LEVU.

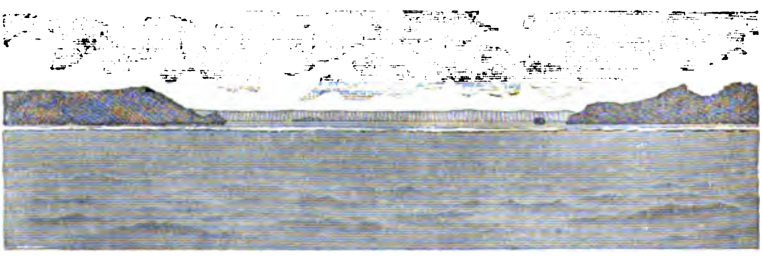
southern faces of Ongea Levu are studded with islets and rocks, which, like the ridges of the islands, consist of elevated limestone. They are most numerous off the wide and deep bay on the southern face of the larger island, and extend across the channel separating Ongea Levu and Ongea Ndriti (Plate **94**). The outliers extending south from the former island connect with those stretching north from the opposite face of the smaller island.

The mushroom-shaped rocks and islets also extend along the western face of Ongea Ndriti, but they are not as numerous as on the northern face. On many of the islets are found a few straggling palmettos, identical with those growing on the principal island. The islets and rocks as well as the shore cliffs are deeply undercut, and the surface is deeply pitted, honeycombed, and full of potholes and caverns, and presenting the appearance so characteristic of the weathered coralliferous limestone wherever we have found it in Fiji. It seems, however, as if the erosion and denudation, and the accompanying weathering, had been more intense as we proceeded southward along the windward islands of Fiji. The islets and rocks remaining as evidence of the former connection of the islands of this group are perhaps as good illustrations as any we have seen of the process which has been going on to reduce to its present proportions the original reef flat or island, which probably once covered the whole of the area of the Ongea Lagoon. The bottom of the lagoon is made up of coral and coralline sand. Half a mile from the northeastern horn of the outer reef of Ongea rises a sharp submarine peak, of which only the rock rising on the western edge remains, and on which has been formed the small circular reef of Thakau Teteika, about three quarters of a mile in diameter; while to the southeast, distant about three miles and a quarter, rises Nuku Songea, a triangularly shaped atoll enclosing a shallow lagoon with a low sand key at its northern extremity.

Fulanga.

Plates 22, 22ᵃ, Figs. 4, 5, and Plates 80-84.

Fulanga is an elliptical island deeply indented on its southwestern face (Plate **22**), along which rises a ridge of elevated limestone to the height of 240 feet. This tertiary limestone rock has been elevated to a height of 260 feet at Quoin Hill, on the northeastern face of the island. The "Sailing Directions" (p. 214) represent Fulanga as "of volcanic and

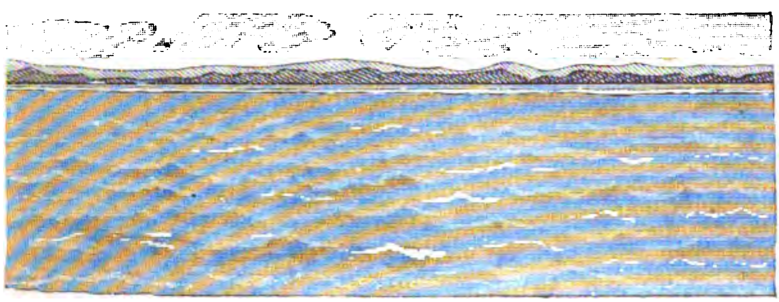


ENTRANCE TO FULANGA.

coral formation, and the circular shape of the island leads to the supposition that it is the rim of an extinct crater." What I have seen of Fulanga shows no trace of volcanic rocks, though they may exist on the southwest shore, which we did not see. Mr. Gardiner,[1] who visited Fulanga, classifies it among the limestone islands. It is quite natural

[1] Proc. Cambridge Phil. Soc., Vol. IX. Part VIII. p. 458 (1898).

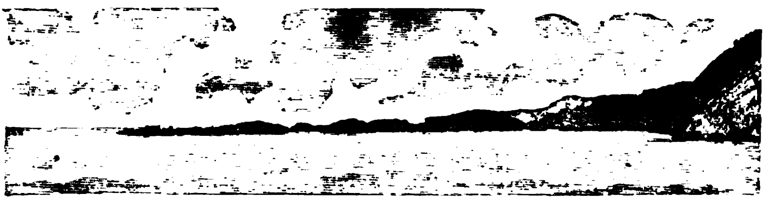
that the honeycombed pitted pinnacles of hard ringing limestone should be mistaken by inexperienced observers for volcanic clinker-like rocks, and the locality described as volcanic, especially when taken in connection with the crater-like aspect of the sounds. The island is surronnded by a fringing reef nearly a mile in width in some places, and with a passage forming a shallow and very narrow lagoon with a depth of four to five fathoms between the outer reef flat and the shore line along parts of the eastern and of the western face of the island. There is a narrow passage (Plate 82) on the northeastern face into the interior basin, but too shallow to have admitted the "Yaralla." In addition there are also a number of openings between the numerous islands and islets into which the elevated limestone ridge has been cut up (Plate 80). Through all these the current flows with considerable velocity (three knots). The



EAST SIDE OF FULANGA.

interior of the basin is full of islets and of rocks, mushroom-shaped or dome-shaped, all deeply undercut and all consisting of the same elevated limestone of which the outer ridges are composed (Plate 81). These islets and rocks are of all sizes and shapes, some of them nearly half a mile in length; and they are found in every part of the basin (Plates 83, 84). The greatest depth of the interior basin is ten fathoms, with an average of five to six.

Although the general appearance of Fulanga is much like that of an extinct crater, yet its formation is due to other than volcanic agencies. The whole of the area of Fulanga must formerly have been covered by a bed of raised coralliferous limestone. The lower parts of the eastern face of this elevated flat became cut up into islands and islets, allowing the passage of the sea, and it has little by little eaten into the body of the elevated limestone, forming an extensive inner basin four miles in length by two miles wide, leaving the basin studded with innumerable islets and rocks (Plates **83**, **84**) such as I have already mentioned. These islands have usually vertical faces; many of them are conical, dome-shaped, or mushroom-shaped, like the islands and islets inside of the interior basin. A similar process has been going on off the northern point of Fulanga, south of Quoin Hill, where the conical and dome-shaped and mushroom-shaped islands and islets and rocks are seen to pass gradually from conical or dome-shaped bluffs along the shore line into the negro-heads of the outer reef flat off that point. This process of disintegration must have been similar in every respect to that which has formed the sounds in the Bermudas, eating small bays into the faces of bluffs inland, these becoming circular with time, with only a narrow opening, and finally leaving merely a narrow ridge or parts of ridges surrounding a central basin resembling an atoll.



FULANGA SOUTH OF QUOIN HILL.

If the process which has been shaping Fulanga had been going on longer the result would have been a low ridge on the southwestern face of an elliptical outer reef flat, with an enclosed lagoon full of islets or rocks or heads, and here and there perhaps an island or islet indicating the former existence of the elevated coralliferous limestone ridge; there being a passage into the lagoon where it now exists, the lagoon as enlarged including the true lagoon and the "Sound" basin, — a condition of things very similar to that found on Oneata, Ngele Levu, Yangasá, Nanuku, and on Vanua Mbalavu. On the faces of the islands and islets forming the eastern ridge of the basin of Fulanga rise vertical cliffs deeply undercut and weathered. The reef flats are full of negro-heads, some of which are of considerable size. The reef flats are everywhere covered with extensive stretches of flourishing corals.

This atoll-like basin has thus in reality been formed by the wearing action of the sea, and subsidence has played no part in its formation; on the contrary, the coralliferous limestone flat covering the basin has been elevated to nearly three hundred feet, and it has been subject for a long period to the action of the atmosphere and of the sea; the one wearing down the limestone land into an inner basin or cutting it out into valleys, and finally into islands and islets; the other encroaching into it from the outside, and eventually forming an interior basin studded with islets, which to all appearance would be a lagoon surrounded by an encircling reef with its heads and patches and islands and islets. And yet it would really be a crater-like basin, a "Sound," which by erosion had become connected with the true barrier reef lagoon, and finally even all trace of the Sound character of the inner basin might vanish with the disappearance of the old shore line, and the existence of only islets to indicate the former land area.

In the case of Fulanga, Gardiner [1] has well described the action of the sea both as a solvent and as a disintegrating factor in reducing the rocks and islets to mushroom-shaped structures, and in the great undercutting of the cliffs, of which he gives the same illustration as that I give here, which was kindly furnished me by the Hon. W. L. Allardyce. He says: "The final result should be a perfect atoll reef just awash, the land being dissolved away while the living reef round it continues to grow." So it does, but the reef has played no part in the shaping of the atoll, the lagoon of which owes its existence to the formation of the interior Sound by the decomposition of the elevated tertiary limestone reef mass, and has no connection with the recent coral reef growing upon the reef flats or external platform of submarine erosion.

SOUTHEAST POINT OF MARAMBO.

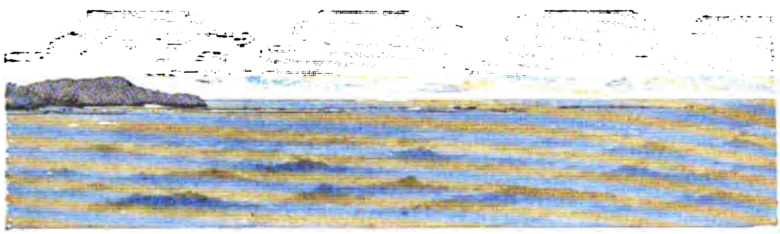
Marambo.

Plate 22.

Marambo is a small circular island about three quarters of a mile in diameter (Plate **22**). It is composed of elevated limestone rising to 160 feet in height. It is surrounded by a fringing reef fully a mile in

[1] *Loc. cit.*, p. 459.

width off the northern extremity of the island. Off the southwest face of the island there is a shallow incipient lagoon. There is a large crack running through the peak of the highest point of the island near the southern point, as if the sea face might scale off at any moment and form a vertical cliff. There is a fine vertical cliff along the northeast point of the island over 100 feet in height, deeply undercut. From the lower edge of this cliff numberless negro-heads extend over the surface of the fringing reef flat, which is covered by large patches of flourishing corals.



NORTH POINT OF MARAMBO.

Dana and Darwin both speak of fissures passing through the shore shelf reef. The fissure we saw at Marambo I attribute to the giving way of the shore bluffs from the undermining preparatory to its shaling off.

Wangava.

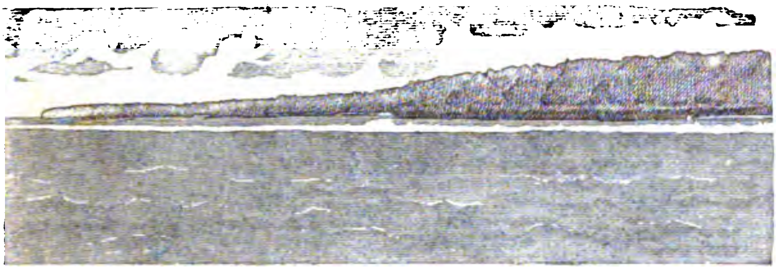
Plate 22.

Wangava, as seen from the passage between it and the northern extremity of Kambara, appears to be composed of two parallel ridges of limestone, elevated to a height of nearly 300 feet. The island is steep to on all sides, steep cliffs forming its eastern and western faces. It is surrounded by a wide fringing reef (Plate **22**) except off the north face, where it becomes broken up into coral heads and patches.

Vatu Leile.

Plates 9, 17[a], Figs. 1-4, and Plates 100-102.

Vatu Leile, the westernmost island of the group we examined, is triangular in shape, with a small lagoon extending along the eastern and the northern faces of the island (Plate **9**). The lagoon is comparatively shallow, not having anywhere a depth greater than five fathoms. Nearly the whole lagoon is covered with patches of corals and of reef rock, especially in the southern and western parts. The island of Vatu Leile is a mass of elevated limestone rock, rising at the southern extremity to bluffs of about 30 feet on the western side. The series of bluffs forming



WEST SIDE OF VATU LEILE.

the western shore gradually increase in height as we go north, where at the most westerly point the bluffs are more than 100 feet in height (Plate 100).

The bluffs of the western coast are vertical faces with rounded summits full of cavities and alternate with short coral sand beaches. On many parts of the fringing reef edging the west coast there are still left small mushroom-shaped rocks, fragments of elevated limestone rock once form-

NORTHWEST POINT OF VATU LEILE.

ing a part of the main island. The northern extremity of the island is full of caves. Judging from the color of the water, the outer slope of the reef flat towards deep water appears to be very gradual. The whole island slopes gently to the eastward, having gradually been denuded and eroded so as to form a low east shore line, with extensive flats off the north-eastern point. The west shore is protected by a fringing coast reef varying in width from a few yards to 300 or 500 yards, or even disappearing entirely along some of the beaches, with many areas of smooth impounded water within the fringing reef flats. The north side of the lagoon is protected by an outer reef flat fully half a mile wide in some places. On it corals are flourishing. There are two passages into the lagoon, with about ten feet of water in the channel. On the eastern side the outer reef runs parallel with the coast, gradually becoming wider towards the south, where it forms a wide coral flat connecting as a fringing reef the outer reef with the low southern part of the island.

To the west of the lee passage are the small island of Vatu Savu (Plate **101**), consisting of a larger low rock of elevated limestone deeply undercut and pitted and honeycombed, and of three other mushroom-shaped rocks of the same structure. Between the lee and the weather passage are the islands of Vatu Levu and the cluster of rocks Vatu lai lai (Plate **102**), similar in structure and in appearance to Vatu Savu. These islands and islets are all situated upon the flat of the outer reef. The whole reef flat is further studded with negro-heads, the remnants of former islands and islets of elevated limestone.

The presence of these islands, islets, and rocks, as well as the existence of the extensive flats off the east coast, clearly indicate the manner in which denudation and erosion have transformed the greater Vatu Leile which once may have covered the whole area of the lagoon, leaving only a part of the main island, with the islands and islets on the outer reef flats and the innumerable patches of corals flanking the inner edge of the outer reef. There is a strong current flowing out through the passages of the northern line of the outer reef.

THE SOUNDS OF FIJI.

Plate 22.

Fulanga is also interesting as illustrating the formation of an atoll by the same causes which have produced the Sounds in the Bermudas.[1] In the case of Fulanga we have a ring of elevated coralliferous limestone raised by volcanic agencies to a height of nearly two hundred feet. The whole area of Fulanga was probably once covered by coralliferous limestone, forming an island resembling Kambara or Mango. The island was, judging from its present condition, highest on the northern side, with

[1] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 2, 1895, p. 231; also Bull. Mus. Comp. Zoöl., Vol. XXVIII. No. 2, 1896, p. 29.

summits nearly as high on the southwest coast, and sloping seaward towards the east (Plate 80). Atmospheric agencies gradually reduced its height, cutting out at the same time an interior basin, the eastern rim of which (Plate 81), being lowest, was soon denuded and eroded in part. One can readily see (Plate 22) how longer denudation and erosion would reduce the existing Fulanga land to a few large islands left isolated in the interior of an encircling reef and connected only by a few mushroom-shaped or conical islets, the interior of the lagoon being dotted with coral heads, the recent corals on the outer edge of the submarine flat forming a reef crust of moderate thickness. This coral rim has been broken through, and the action of the sea has gradually hollowed out in the interior a circular sound resembling an extinct crater (Plate 22), which has arisen solely from the disintegration of the inner part of the elevated limestone. Many parts of this still exist as small mushroom-shaped or conical islands (Plate 83).

It is also probable that some of the ancient elevated reef flats may have been converted into atolls by causes similar to those which have produced the crater-like Sound of Fulanga. This has perhaps been the case with such atolls as Ngele Levu, and the Oneata, Ongea, and Yangasá groups. In both Ongea Levu and Ongea Ndriti (Plate 22), incipient sounds are forming which will cut these islands into two or more components, each one of which will in its turn be dissected into smaller islands or islets, till finally the remaining land may be all reduced to insignificant islands and islets, as on Ngele Levu (Plate 17), or on Wailangilala (Plate 18), Reid Haven, Vanua Masi (Plate 20), Motua Levu and Motua lai lai, Duff and Adolphus Reefs (Plate 18), or the islets may have totally disappeared and no vestige of the former land area remain except the sunken coral heads and rocks of such atolls as Thakau Levu, Thakau Motu (Plate 22), Thakau Lekaleka (Plate 21), the Ongea Reefs (Plates 20, 21), Thakau Tambu (Plate 20), Thakau Mata Thuthu, and Thakau Vutho Vutho (Plate 17), with the reservation that some of these atolls may be the result of the denudation and submarine erosion of volcanic islets or peaks or ridges, and not necessarily of elevated coralliferous limestones.

Are not islands such as Phœnix, Birnie, Kean, Howland, Baker, and Enderbury, which have depressions in the centre and no lagoons, islands which are gradually being denuded to the level of the sea, and the next stage of which will be the formation of a lagoon (sound) by the cutting in of the sea across the rim at one or more points, forming islands or islets round the lagoon? We can thus explain the peculiar formation of these islands without having recourse to subsidence. Yet other writers upon coral reefs would look upon some of these islands as instances of raised atolls.

The gradual transformation of islands, composed either wholly or in part of elevated limestone, into islands with large interior sounds like Fulanga can be readily followed by examining such islands as Wangava (Plate **22**), Tuvuthá, Naiau (Plate **20**), or Vanua Vatu (Plate **21**), in which the interior basin is still surrounded by a high rim. Next followed such islands as Mango (Plate **19**), in which the interior basin has at one extremity been transformed into a diminutive sound; then follow such islands as Namuka (Plate **22**), the rim of the basin of which has been eroded so as to leave only parts of it, and the outline of which has been deeply cut into by a large outer sound. We pass next to such a group as Ongea (Plate **22**), and next to such groups as Yangasá (Plate **22**), of which the rim of the basin is represented only by four small islands scattered within the encircling reef; next to Oneata and Aiwa, where a single island, comparatively small, represents the former extent of the elevated limestone area of those groups. And a still further stage of erosion and denudation is represented, as stated above, by Ngele Levu, Wailangilala, and other atolls in Lau.

Vatu Leile (Plate **9**) must have sloped very rapidly eastward to have attained its present condition, and we can readily follow it to a time when it will be flanked on the west side by a line of narrow islets very similar to those now existing on the north side of the lagoon. When the island and islets in Vatu Leile, Ngele Levu, Wailangilala, Katavanga, Reid Reef, Aiwa, Oneata, Yangasá, and Ongea have disappeared by subsequent erosion, it will be wellnigh impossible to detect the nature of the substratum upon which the modern reef is growing. At that time the lagoon will probably have become gouged out much as Ngéle Levu has been. A similar difficulty will naturally be encountered, though at a later period, in determining the geological composition of the substratum underlying the modern coral reef in the atolls of Wakaya, Makongai (Plate **15**), Mbengha (Plate **8**), North and Great Astrolabe Reefs (Plates **9**, **10**, **11**), Budd Reef (Plate **18**), Totoya (Plate **16**), Kimbombo (Plate **19**), Nairai (Plates **12, 14**), Komo (Plate **22**), and others, when the islands now existing on the edge or within the encircling reefs have disappeared from denudation and submarine erosion.

This is another instance of the great variety of causes which have been active in producing the present physiognomy of the reefs of the Fijis, and shows the impossibility of assigning any one factor, like subsidence, for instance, as is done by Dana and Darwin, as the single cause for the formation of the many different kinds of atolls and of barrier reef islands to be found in the Fijis.

THE TERTIARY ELEVATED LIMESTONES OF FIJI.

The existence throughout Fiji of numerous platforms of submarine erosion at average depths varying within very moderate limits seems to indicate a condition of approximate equilibrium as far as either elevation or subsidence is concerned. The elevation of the limestones of late tertiary age clearly indicates that the origin of the greater number of the Fiji Islands dates back approximately to that period. This is undoubtedly the case with the range of islands known as the Lau or Eastern Archipelago of Fiji. With them we should include the more northerly islands, the group to the east of Ngamia, and of Budd Reef, including Thikombia.

It is more difficult to determine the age of the larger islands, Viti Levu and Vanua Levu, as well as Taviuni, Kandavu, and the volcanic islands of the Koro Sea. We may assume with a certain degree of probability that the age of such islands as Nairai and Ngau corresponds with the age of the volcanic rocks which have lifted the islands of the Lau group to their present altitude. But in Viti Levu and Vanua Levu the problem is more complicated. While elevated coralliferous limestones of late tertiary age occur along the shores of Viti Levu evidently of the same age as the limestones of Lau,[1] yet there is evidence of the existence of older rocks as a nucleus of the larger Fiji Islands. So that until the geology of Viti Levu and of Vanua Levu has been more accurately studied, we must leave their age undetermined; but enough is known of the geology of the shore line to show that the existence of the great barrier and fringing reefs along the shores of Viti Levu and of Vanua Levu gives no evidence that the great barrier reefs of these islands owe their origin to the gradual subsidence, during our epoch, of the islands themselves.

The existence of the tertiary elevated coralliferous limestone at so many points in the Fiji Archipelago (Plate 2) seems to indicate a huge limestone bed of great thickness and extent, formed during tertiary times, along the flanks of ancient volcanic islands, and elevated by subsequent intermittent volcanic action during more recent times over areas of

[1] Horne (A Year in Fiji, London, 1881, p. 165) says that in Viti Levu and Vanua Levu sedimentary or limestone rocks are found on all mountains.

varying dimensions, — areas which might be of considerable extent, like the Exploring Isles, the Argo Reefs, or smaller areas, like Yangasá, Oneata, Ongea, Fulanga, and the like, or smaller peaks forming atolls of very limited circumference, like Wailangilala, Nuku Mbasanga, or isolated limestone rocks of still smaller dimensions, like Vekai, Tavunasithi, and others.

Of course numerous soundings among the islands of the Eastern Archipelago of Fiji are needed to ascertain the existence of a more or less continuous plateau of coralliferous tertiary limestone deposited either by accretions upon its surface or formed during subsidence.

I brought to Suva a complete diamond-drill boring apparatus and a competent man to superintend the work, Mr. William Eyers, recommended to us by the Sullivan Machine Company of Chicago, from whom the apparatus was obtained. A comparatively small hand machine was sent, capable of drilling to a depth of from four to five hundred feet; an oil motor was also provided to expedite the work with increasing depth.[1] This machinery had been shipped when information reached the United States that Professor David of the University of Sydney had left for Funafuti in charge of an expedition to take up the work where it was left by Professor Sollas, the head of the expedition, assisted by the council of the Royal Society of London.[2] The day before leaving Cambridge for the Pacific, we heard that Professor David's party had succeeded in reaching a depth of nearly 600 feet, the bottom being still in coral. This information seemed to settle the coral question, and all I hoped to accomplish was merely to confirm the work of Professor David by boring in some other district. Subsequent information received from him leads me to think that the matter is not so simple as represented by the newspapers, and from what I have seen thus far in the Fiji Island reefs I can only conclude that the boring at Funafuti has settled nothing, and that we are still as far as ever from having a general theory of the formation of coral reefs. In fact, with the present information obtained in Fiji, I should never have thought of boring in the atolls of that group, for reasons which will be given presently.

This evidence shows that any result obtained would merely indicate the thickness of the former elevated limestones at any particular point; information which could have no bearing on the main question, if I am

[1] I have to thank the Trustees of the Bache Fund of the National Academy of Science at Washington for an appropriation of $1,200 towards defraying a part of the expenses of the boring.

[2] Proceedings of the Royal Society of London, March, 1897, p. 502.

correct in my interpretation of what I have observed; information, in fact, which may be obtained as one steams along, without the trouble or cost of boring. Should I be correct in my inference, I am inclined to look upon the boring at Funafuti much in the same light, and to assume that that island is also in an area of elevation, as well as others in the Ellice group, and that the great thickness of coral obtained was reached in the base of an ancient limestone, and that the results obtained by the boring there do not assist us in any way in corroborating the theory of subsidence as essential to the formation of atolls.

The evidence which has been brought forward regarding the great thickness of modern reefs, as postulated by Darwin, from that of the fossil coral reefs existing during former geological periods, seems to me to be of little value. Langenbeck[1] and von Lendenfeld[2] have both urged this point. The former has given an excellent *résumé* of the subject of these ancient reefs, although he has no personal knowledge of recent reefs. All that can be said at present is that these so called fossil reefs are coralliferous limestones of great thickness, which first occur in the Devonian; they are little developed either in the Permian, or Trias, or Lias. They are again well developed in the Jurassic period, less so in the Cretaceous, and increase in Tertiary times. That parts of some of these coralliferous limestone masses represent reefs there can be little doubt, yet the observations we made in Fiji regarding the coralliferous elevated Tertiary limestones, which have been considered as elevated reefs of the present epoch, only show how guarded we should be in an expression of opinion as to what constitutes a fossil reef, — I mean a fossil fringing or barrier reef, or a fossil atoll, — when we are not able to decide that point in the reefs of to-day, and when one set of observers claims that the Tertiary elevated limestones represent elevated atolls, while the other set clearly shows that these elevated limestones have played no part in the formation of the recent atoll, or barrier reef, but have merely built up the substratum upon which the moderately thin crust of recent reefs has established itself.

Granting, even, as is very probable, that when these Tertiary limestones were formed they were formed in great part by subsidence, and in part by accretion from the carcasses of the invertebrates living upon their surface, this would in no way help us to a satisfactory

[1] Langenbeck, R.: Die Theorien über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für Physische Fragen. Leipzig, Abschnitt IV.

[2] Nature, May, 1890, p. 29. See also the interesting note by von Fritsch, quoted by Krämer, *loc. cit.*, p. 38.

explanation of the formation of atolls and of barrier reefs by the growth of the corals of the present epoch. Nor would the geological evidence of the great thickness of similar limestones in past periods be of any assistance in the solution of the problem if our explanation of the formation of atolls and of barrier reefs upon platforms of submarine erosion is correct.

Certainly the analogy of the association of volcanic rocks and so called reefs in the Devonian and Trias with similar association in the Pacific has no value, as is suggested by Frech[1] and Langenbeck. The substratum upon which corals may grow depends upon the geological structure of the country and its latitude. Such an analogy would throw out in great part the reefs of Australia, those of Florida, of the Bahamas, of Honduras, and of the northern coast of Brazil, which are not in volcanic regions, and where the substratum is either Cretaceous or Tertiary.

The only evidence we have of the great thickness of coral reefs, such as is required by the Darwinian theory of the formation of atolls and of barrier reefs, is based upon the great thickness of the so called elevated reefs observed in the Pacific by Dana, Darwin, and others, and upon similar observations in Cuba and other parts of the West Indies, and upon the evidence of the great thickness of the reefs of the Dolomite. That the latter are true coral reefs is more than doubtful. Those rocks are probably great masses of limestone similar to the huge deposits of so called elevated reefs of the West Indies and of the Pacific. The evidence obtained by boring, and from recent elevated reefs, shows that the modern coral reef attains but a moderate thickness well within that of the depth at which reef corals grow. The limestones form the basis or substratum upon which the recent reefs have obtained a footing. The elevated reefs of Cuba and of the West Indies have been shown to be Tertiary coralliferous limestones, and the same is the case with the elevated reefs of the Pacific, if we can judge of their age by that of the elevated coralliferous limestone reefs resembling them observed by me in Fiji.

The central depression, noted as characteristic of the summit of so many islands consisting of elevated coralliferous limestones does not show these islands to be elevated atolls as has been supposed. The summit basin representing the former lagoon of the island has been formed since the elevation of the island by atmospheric agencies. This basin is a gigantic banana-hole, as such depressions are called in the Bahamas,

[1] Neues Jahrb. f. Mineral., 1892, Pt. II. p. 173.

formed by the carrying off the limestone in solution in the pools or ponds in the summit basins, — basins which with age become deeper and deeper, forming thus depressions which in some instances have been mistaken, in the one case for extinct craters, in the other for the lagoons of elevated atolls.

I would refer to the description of such islands in Fiji as Mango, Kambara, Tuvuthá, Naiau, Fulanga, and others, as evidence supporting the explanation here given of the formation of the so called elevated atolls. Of course I do not mean to assert that an atoll cannot be elevated as such, nor that such atolls may not exist. I merely wish to assert that the summit basins of islands formed of elevated coralliferous Tertiary limestones in Fiji are islands in the first stage of disintegration, passing gradually from such types as Naiau[1] and the like to islands like Mango, then to Fulanga, next to the Yangasá cluster, then to Ngele Levu, and finally to Motua lai lai and the like.

The steepness of the slopes of coral reefs has been assumed to be due to the growth of corals, and has generally been taken from old and unreliable soundings, as has been stated by Admiral Wharton[2] and others. The great depths are generally soundings so far off from the coral islands as not to give any accurate information.

The actual slopes of coral reefs which have been measured are very few, and the slopes given are invariably those of the underlying substratum, which may or may not be steep, and the inclination of which has no bearing on the angle of the steep outer slope of recent coral reefs, which usually reaches only to the very moderate depth of twelve to fifteen fathoms.

It seems to me that the calculations which have been made by Darwin in regard to the thickness of coral reefs, depending as they do upon the assumption that their great thickness has been formed by subsidence, and that this thick mass rests upon the continuation of the inner land slope under the coral reef, are assumptions which cannot be proved, or have not been proved. We should get a totally different result, that of a comparatively thin crust, if we assume that the land slope commences at or near the outer edge of the reef wherever the outermost negro-heads have been found. And in a great many cases, the steepness of the sea face is no greater than the slope of the mountains of the adjoining land. I have already called attention to the fact that

[1] Naiau itself having become depressed in the centre by chemical and atmospheric erosion.

[2] Nature, June 19, 1890, p. 172.

off the south coast of Cuba we have along the sides of Bartlett Deep fully as steep a pitch as that of any coral reef.

Gardiner[1] has noticed the atoll-shaped shoals inside the great barrier reef of Fiji (Plate 23[a]), and compares them to the smaller atolls inside the large atolls of the Maldive group. See also the Serpuline atolls of the Bermudas,[2] which hold the same relation to the lagoon inside the outer barrier as the atoll-shaped shoals just mentioned hold in Fiji, and they certainly are not due to the effects of the débris of the outer reefs of the present day, as is claimed by Dana.

As long as it was taken for granted that the coral reefs of the present day were of great thickness, it was natural to compare them with the great beds of coralliferous limestones occurring in past ages from the time of the Devonian to the end of the Tertiary period. While there is abundant proof that some of these limestone beds have been formed during a period of subsidence, there is also ample proof that they must have greatly increased in thickness by accretion. But it does not follow from this that atolls and the lagoons of barrier reefs have been formed during a period of subsidence, now that we know that a great many of the coral reefs of the present day attain a comparatively moderate thickness, well within the bathymetrical limits at which reef building corals thrive. Nor is there anything to prove that these ancient limestones represent such modern structures as the atolls, or bordered the lagoons of barrier reefs, and even if they did it is more natural to suppose that the lagoons of these ancient atolls, as well as those within the ancient barrier reefs, must have been formed by the same agencies which have shaped the atolls and the lagoons of barrier reefs in our days. So that the analogy between ancient and modern reefs, such as is upheld by Dr. R. von Lendenfeld,[3] while undoubtedly true as far as it applies to the formation of beds of coralliferous limestones of great thickness, yet has no application to the actual formation of the lagoon of an atoll or of a barrier reef.

This still leaves open the question of the mode of formation of such thick masses of coralline and coralliferous limestone, which, though they may originally have been formed partly by subsidence, may also have been formed partly by the gradual pushing out to seaward of the outer edge of a reef increasing both in height (depth) and in width by the constant pushing out of the mass of débris and of blocks detached from the

[1] *Loc. cit.*, p. 498.

[2] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 2, 1895, p. 258.

[3] Nature, No. 1071, May 8, 1890, p. 29.

outer edge upon which corals may flourish and spread seaward, when the talus has reached the depth at which corals can grow. I am inclined to think that the examination of such a reef will alone give us an idea of the way in which such thick masses of coralliferous limestones were formed, — most probably by a combination of subsidence, of accretion, and of lateral expansion.

What the exact age of the elevated limestones is, I am as yet unable to state. Their aspect and position show them to be of considerable age, and probably antecedent to the present period, and in many ways they resemble some of the late tertiary elevated limestones I have found on the north coast of Cuba. The great thickness which the elevated coralliferous limestones attain in this group, at least 800 feet, also shows that it may have been deposited during a period of subsidence, but not a period of subsidence in our epoch, or which could have had any effect in shaping the outline of the islands of the Fiji and their accompanying reefs.

Whether the elevation of the Fiji group corresponds in time with that of the northern part of Queensland, I am unable to state. I can only suggest that it is not improbable that the elevation of Queensland and of the islands to the east of the Solomon, New Hebrides, etc., including the Fijis and Samoa, may have been synchronous, and that these islands have, like northern Queensland, been subject to an immense denudation and erosion, reducing them to their present proportions. The elevation having probably, as in northern Australia, been preceded in still earlier geological times by a great depression, during which the thick beds of coralliferous limestone may have been formed. Judging from some photographs I have seen, I should feel inclined to consider the atolls of the Paumotus to have been formed by causes similar to those which have shaped those of the Fijis.

The Tonga Islands as described by Lister[1] are arranged by him in three divisions: (*a*) purely volcanic islands; (*b*) islands formed of volcanic materials laid out beneath the sea and since elevated, with or without a covering of reef limestones; and (*c*) islands formed entirely of reef limestones.

The islands of the Vavau group consist entirely of limestone, the formation of which must have been at least 300 feet thick. The islands are flat-topped, and the majority stand at one of three levels of elevation. Lister[2] figures the terraces of the islands to the south of Vavau. At

[1] Notes on the Geology of the Tonga Islands. By J. J. Lister. Q. J. Geol. Soc. of London, Vol. XLVII. p. 590, 1891.

[2] *Loc cit.*, p. 608.

Fiji the only signs we saw of terraces were at Yangasá. The terraces in Fiji are most obscure, and what we find of elevation would seem to indicate sudden and rapid elevation without periods of rest such as occur in the Vavau Islands of the Tonga group, or in Cuba,[1] where the terraces are so well marked, especially in the vicinity of Cape Maysi.[2]

Lister speaks of the peculiar shape of the groups, penetrated by long, narrow, and deep inlets of the sea, a condition of things very similar to that of Ngillangillah, and of the north shore of Vanua Mbalavu in Fiji. Tongatabu is formed of coral limestone throughout, and one often meets with patches of coral, many feet in diameter, on which the lines of Astræoids or Madrepores are seen radiating from a common centre.

Lister calls attention to the basis for the growth of coral reefs which can be formed by such islands as Falcon Island.[3] He also shows that in the Tonga Islands, Tongatabu and Nanuku rest on shallow banks, and where the basis is exposed it is shown at Nanuku and Eua to consist of layers of volcanic material laid out under water.

Darwin and Dana both suggested that the formation of the Tonga Atolls was in a period of subsidence, yet it is asserted in the discussion of the subject[4] by Mr. J. W. Gregory that his theory (Darwin's) was not proposed for areas of coral formation in shallow or rising areas. Why then do Darwin and Dana quote them as examples of their theory? There is altogether too much of that kind of argument in the discussion of that theory. Are Darwin's supporters at liberty to carry on the process of selection till nothing is left of the original statement?

In Samoa and Tonga the volcanoes are still active, and we can, following Lister, actually trace the process of elevation and of erosion which has resulted in Tonga in elevating limestones and volcanic islands similar in every respect to those we have observed in Fiji. Islands in the last named group owe their existence to former volcanic action, the evidence of which is still visible in the existence of the extinct craters of Taviuni, of Thombia, of Moala, and of Totoya, and this volcanic action is to be traced throughout the larger islands of the group.

The description of Eua Island in the Tonga group given by Commander Oldham in Nature of May 22, 1890, p. 95, applies admirably to

[1] A. Agassiz, A Reconnoissance of the Bahamas and the Elevated Reefs of Cuba. Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, p. 110, 1894.

[2] R. T. Hill, Notes on the Geology of the Island of Cuba. Bull. Mus. Comp. Zoöl., Vol. XVI. No. 15, 1895.

[3] Falcon Island is stated to have disappeared during an eruption in August, 1898.

[4] Q. J. Geol. Soc. of London, Vol. XLVII. p. 590, 1891.

the conditions which I imagine to have existed in the Fijis,[1] although the terraces indicate two periods of elevation, with one of rest, during which an interior basin similar to the central basin of islands like Kambara, Wangava, and the like, in Fiji, was formed by atmospheric agencies probably.

The rocks underlying the coralliferous limestones are stated by Professor Judd to be igneous rocks, but not modern volcanic material. He says, "They are suggestive of ancient volcanic masses that have been exposed at the surface by denudation, . . . and it is quite incorrect to quote examples like this as lending support to the view that all oceanic islands are of volcanic origin."

Speaking of Eua, which belongs to group (*b*), Murray according to Lister is of the opinion that the organic deposits of the island are old, yet there is no satisfactory evidence to refer them to the Tertiary period.

Niue or Savage Island is an elevated coralliferous limestone island, said to be 200 feet high;[2] the younger Foster considers that the central plain represents an ancient lagoon. It is skirted with enormous caverns.

The figure and description given by Dana[3] of Metia or Aurora Island, one of the Western Paumotus, recalls many of the raised limestone islands of Fiji. In the Hervey group at Atiu similar caverns exist, and they have also been noticed by Captain Beechey at Henderson Island. Its cliffs worn into caverns rise abruptly to about 230 feet on all sides except the south, where the island slopes very abruptly, much as Vatu Leile in Fiji. The surface of Metia, as described by Dana, resembles closely that of Ngele Levu, and he describes the wide shore platform, "resembling that of the low coral islands" and the modern reef about its margin.

It will be interesting to see if the great masses of coral blocks, figured and mentioned by Dana[4] may not throw some new light on the nature of the substratum of some of the Paumotus, where he observed them.

The sections of the small island of Masámashu in the Red Sea[5] do not seem to me to indicate subsidence, as is stated by Bonney (p. 312).

[1] See also the account of Eua, by J. J. Lister, in Q. J. Geol. Soc. of London, Vol. XLVII. p. 590, 1891.

[2] Sailing Directions, Pacific Islands, Vol. II. p. 54.

[3] *Loc. cit.*, p. 193.

[4] *Loc. cit.*, pp. 179 and 203.

[5] Nature, Vol. XXXVI. p. 413.

On the contrary, judging from Fiji analogy, the section indicates the elevation of a submarine bank of coralliferous limestone and its subsequent denudation, and the forming of an enveloping reef on its summit having no relation with the nature of the deeper sea slope.

We collected a number of corals from the elevated limestone rock at several localities along the south and west coast of Viti Levu, at Suva, Ngele Levu, Kambara, Ongea, Ngillangillah, and Oneata. I found it impossible to determine whether the corals were *in situ*, or had been rolled or dropped along the sea face to form a talus. The difficulty of determining this without very considerable blasting at the base, the face, and along the exposed slopes of the elevated coralliferous limestones, is very great.

The collecting of corals from the exposed faces of the cliff was almost hopeless with our appliances. The faces have become extremely hard, a hammer produces no impression, and the corals are so well embedded as to make it impossible to cut them out.

It seems impracticable, except where one can actually see the corals grow along a slope, or on a patch or the sides of a head, to determine in the elevated reef rock if they are still in their natural attitudes. Madrepores and Pocillopores grow in all kinds of position; so do the heads of Astræans, Mæandrinas, and other massive corals. Furthermore, the spaces between coral patches and heads and individual masses of coral reef are filled either with sand, corallines, or fragments of dead corals. We can easily see the difficulty of recognizing the former condition of corals now embedded in a homogeneous mass of hard ringing limestone, in which the corals often exist as more or less indistinct solidified masses, barely indicating the genus to which they belong. The coral and coralline sand have become solidified into a close limestone ringing to the hammer. Large spaces have become impregnated with the red earth, characteristic of coral limestone formations, and the masses of coral fragments form a breccia or puddingstone of corals of the species which once flourished on the reef. Masses of Nullipores and Orbitolites are similarly cemented, or form the connection between the individual masses. The whole again is more or less cavernous, representing either spaces originally existing on the reef, or cavities which have been formed by the percolation of water through the mass. As far as I have examined the corals collected from the elevated limestones, they appear to belong to the same genera as those now living.

A careful and extended examination of one of the elevated coralliferous limestone reefs, as at Vanua Mbalavu or Kambara or Mango, for instance, where we can begin the study at the very base of the elevated limestone reef at its point of contact with the underlying volcanic rock, will teach us a great deal regarding the interior structure of a coral reef. This we can follow to the surface, or nearly so, by following the faces of exposed cliffs or the slopes of the ridges. Of course, the uppermost part of the reef rock, that which formed the original surface of the reef, will have been denuded and eroded to a considerable depth. But it ought to be possible from the study of an extensive area of an elevated reef, both vertical and horizontal, to settle the question of the growth of a reef seaward by its gradual extension upon a talus formed at a comparatively shallow depth (say twenty fathoms) from the fragments and masses which have dropped at the foot of the sea slope of the reef, after having been detached by the action of the breakers from the edge of the reef. It is natural to suppose that there must exist at the base of the reef a number of coral masses, judging from the multitude which are thrown upon the sea face of any modern reef when exposed to violent breakers.

Dr. William H. Dall[1] has been kind enough to examine the fossil mollusks which I collected from the elevated limestone reefs in the Fijis. He confirms the impression I had formed of their late tertiary age. Dr. Dall writes: "The fossils comprise Turbo, Cassis, Lithophaga, Macha, Tellina, Meretrix, Dosinia, Chama, Pholas, and fragments of Pecten. None of the genera are extinct. The rock, however, looks decidedly too old for Pleistocene. I should say the fossils were younger than Eocene, and might be either Miocene or Pliocene."

The boring which I started at Wailangilala Island in the atoll of the same name reached at forty feet a limestone similar in all respects to that composing the elevated reefs we had observed at Ngele Levu, at Vanua Mbalavu, at Mango, at Yangasá, at Oneata, at Ongea, at Kambara, at Vatu Leile, and at different points along the eastern, southern, and western shores of Viti Levu. At some points the elevated limestones attain a height of over 1,000 feet (Vatu Vara Island 1,030 feet), and the volcanic rocks underlying the elevated limestone reefs were observed at Vanua Mbalavu, at Mango, at Kambara, and at several points along the southern and western coast of Viti Levu. A renewed examination of the elevated reefs of the Paumotus, of the Friendly Islands, of the Gilbert, Ellice, and other groups of atolls in the Pacific will be needed to determine their age and correlation to the Fiji elevated limestones. At any rate, it is evident that the tertiary coralliferous limestones of Fiji have not played any part in the formation of

[1] See Am. Journ. Science, Vol. VI. p. 165, 1898.

the atolls or islands encircled by recent coral reefs beyond forming the substratum upon which the recent corals have grown and established themselves as a comparatively thin crust.

The underlying limestones have performed exactly the same part as the volcanic substratum in other islands of Fiji, such as Totoya, Kimbombo, Wakaya, Makongai, Moala, Nairai, Ngau, and others. In both cases the platform upon the edge of which the corals grow has been prepared by extensive submarine erosion, dating from the time when the limestones were elevated by the volcanic rocks which crop out everywhere in Fiji, — an elevation which was not necessarily synchronous throughout Fiji and may have taken place at several distinct periods, so as to make it often difficult to determine the relative age of the limestones and of the volcanic masses.

Professor David, of the University of Sydney, has been kind enough to assist me in obtaining the services of one of his students, Mr. E. C. Andrews, to collect fossils from the elevated limestones of Fiji. Mr. Andrews has spent a part of the summer in Fiji, collecting material and exploring in detail some of the faces and slopes of the elevated reefs of the Archipelago, and has obtained ample material to determine the age of these elevated limestones.

In the earlier discussions of the thickness of recent coral reefs by Darwin and Dana, no attention was paid to the possibility of the substratum of recent reefs consisting of tertiary limestones. Elevated limestones containing corals of tertiary age were considered as of recent origin and as pointing to a great thickness of modern reefs. It has been shown in Florida that the modern reef is not more than about 50 feet thick, and is, according to the borings from the artesian well at Key West, succeeded by tertiary limestones, in which corals occur at intervals to a depth of 2,000 feet.

It has been stated by Dana and others that the borings from the artesian wells at Honolulu, to the rear of the shore line of the fringing reef of Oahu, indicate a great thickness of modern reef corals. These statements are based upon the examination of samples of finely ground particles of limestone accompanied by an occasional fragment of coral, the age of which has not been determined. The statements are further supported by the evidence of Mr. J. A. McCandless, the engineer in charge of the boring, who asserted to both Mr. Dana and myself that in boring all his wells the tool passed through a great thickness of corals, at various levels. During my recent visit at Honolulu, I was so fortunate as to be on the spot where Mr. McCandless was boring a ten-inch well, about

2,500 feet from the shore line, and perhaps seven feet above high water mark. Down to a depth of 80 feet nothing but recent reef coral rock was encountered, but from that point to a depth of over 300 feet the limestone passed through was of a very different character. It contained but few corals, being composed almost entirely of the shells of mollusks, mainly bivalves. The rock was white, chalky, and resembled in every way the rocks of the Vicksburg age of Florida and of Yucatan; but its age has not yet been accurately determined. Enough, however, is clear to show that the limestones which form the substratum upon which rests the recent fringing reef of Honolulu do not belong to the present period. Mr. McCandless assured me that limestones like those I had the opportunity of examining while the boring was going on are identical with those to which he called Mr. Dana's and my attention in 1888, and that until I pointed out to him that the white limestone was almost wholly made up of mollusks he had only paid attention to the occurrence of occasional corals, and supposed that the lower limestone formed the continuation of the recent modern reef. But, as I have stated, this lower limestone differs from reef rock both lithologically and in its being mainly made up of fossil mollusks.

It is very clear that when boring in a coral reef district in which it is difficult or impossible from other data to determine what geological changes may have taken place, or the probable age of any limestone we may pass through in boring, it may be very easy to draw wrong conclusions both as to the age of the limestones and regarding the position of the line of demarcation between the modern coral reef and the underlying older limestone substratum.

If my conclusion is correct, that such atolls in the Fiji Islands as Wailangilala, Ngele Levu, and many others to which I have referred in this report, are formed upon platforms of submarine erosion of elevated tertiary limestones, and if, further, in similar atolls in the Paumotus, the Gilbert, Ellice, and other groups, the substratum underlying the modern coral reef is likewise composed of tertiary limestones, it will become apparent that such borings as those carried on at Funafuti will not help us in any way to solve the problem of the formation of atolls by modern coral reefs. Such a boring, even should it reach the underlying volcanic substratum, will only give us the thickness of the tertiary coralliferous limestone beds forming the substratum upon which the modern coral reef has grown, — a thickness which in the Ellice group can only be ascertained by boring, while in Fiji it can be ascertained approximately from the height of the islands composed of elevated tertiary limestones.

I take it that the "cliffs" mentioned by Sollas,[1] and that the pinnacles described by Gardiner[2] which he calls "the remains of a part of an old raised reef," found on the inner rough zone of the outer reef, are just such masses of tertiary limestone as we found throughout the Fijis.

The shoals described by Gardiner[3] seem to me to be remnants of this elevated reef which have been isolated by submarine erosion, much as in Fulanga and Ngele Levu, and other groups of elevated tertiary limestone reefs in Fiji, upon which corals grow with greater or less luxuriance, the bottom of the lagoon between the patches and knolls being covered with sand.

Gardiner[4] supposed the atoll of Funafuti to have been formed before it was elevated. If I am correct in my interpretation of similar reefs in Fiji, I think, on the contrary, that the low limestone outer platform which now forms the ring of the atoll was once much higher, covered a greater area, and has been gradually denuded and eroded to its present stage, a process which according to Gardiner and my own observations is still going on.

Hedley,[5] as well as Sollas and Gardiner, assumes an elevation of four feet from the presence of dead subfossil corals in the position of life near high water mark. I do not see why the fact that the older limestones of Funafuti form a cone, and have no connection with the recent reef formed upon them, should have any bearing either in favor of or against any theory of coral reefs, even if the formation of the coralliferous limestones of Funafuti could only be explained on the subsidence theory. The lateral growth of the recent reef inwards and outwards is a feature depending, so far as the outer growth is concerned, wholly upon the exterior slope of the atoll, and the lateral expansion towards the interior of the lagoon depends upon a great variety of causes, such as the depth of the lagoon, the character of the islands on the outer edge of the atoll, the nature and depth of the shallower windward passages leading into the lagoon, the position of the outer reefs with reference to the prevailing winds and currents, the geological structure of the substratum upon which the recent reef is growing, and many other causes. As far as the filling of the lagoon of Funafuti is concerned, the views of Gardiner and Hedley are diametrically opposed. The islands may in-

[1] Proc. Royal Society of London, March, 1897, p. 502. Nature, September 24, 1896, p. 517.

[2] Proc. Camb. Phil. Soc., Vol. IX. Pt. VIII., 1898, pp. 430, 431.

[3] *Loc. cit.*, p 434. [4] *Loc. cit.*, p. 438.

[5] Memoir III., Australian Museum, Part I. Sydney, 1896.

crease in width, and encroach upon the lagoon, but that is a different proposition, as shown by Gardiner, from the filling up of the lagoon.

Gardiner[1] assumes that the limestones of the Fijis cannot have had any different origin from that of many of the atolls and barrier and fringing reefs of the present day.[2] But it seems to me that, inasmuch as these elevated limestones are of tertiary age and have been uplifted to heights varying from a few feet above the level of the sea to nearly a thousand feet to form subsequently platforms of submarine erosion upon which the recent reefs have grown, we cannot claim that they have been deposited, as recent corals have been, within comparatively narrow bathymetrical limits, the dolomitization of the elevated tertiary limestone having gone on to a considerable extent, while that of the recent reefs is insignificant.

Gardiner[3] looks upon Naiau, Tuvuthá, and other islands as perfect specimens of raised atolls. I have elsewhere given my reasons for not accepting such a view, and for considering the interior depressions of such "elevated atolls" as huge sinks similar to those formed in the Æolian hills of the Bahamas and Bermudas, and which eventually result in the formation of sounds or lagoon-like depressions. Gardiner[4] does not think it possible that denudation owing to climatic causes could have been of sufficient importance to have greatly affected the position of the summits. It seems to me that the gradation we can trace in the summits and outlines of such old island masses as Naiau, Kambara, Mango, Fulanga, Ongea, Aiwa, and others indicate, on the contrary, a most extraordinary denudation and accompanying submarine erosion. Gardiner[5] himself has given very much the same examples which I used in tracing the gradual changes hinted at above, only he attributes them wholly to the solvent action of the sea, while I am inclined to call into action in addition the effect of denudation and erosion, and to attribute to them a more important share than to the solvent action of the sea in the successive stages of the changes in the elevated limestone land masses, from an island with a fringing reef to a true atoll.

Under what conditions these tertiary coralliferous limestones of great thickness have been deposited is a distinct question from that of the formation of atolls through subsidence by the upward growth of corals during the present geological period. Neither the borings through a coral reef growing upon a substratum of tertiary limestone, nor the

[1] *Loc. cit.*, p. 467.
[2] *Loc. cit.*, p. 467.
[3] *Loc. cit.*, p. 470.
[4] *Loc. cit.*, p. 470.
[5] *Loc. cit.*, p. 471.

examination of the outer edge of a coral reef formed upon a substratum of volcanic rocks, has given us in Fiji any evidence of the great thickness of a modern coral reef. On the contrary, all the evidence I have gathered there tends to prove that a coral reef forms only a comparatively thin crust upon the platform of submarine erosion, whatever be its geological structure, upon which it may have found a footing, — a crust of modern corals of no greater thickness than that within the bathymetrical range of which reef building corals can flourish.

The examination of the conditions under which beds of coralliferous limestone of great thickness have been laid down has little in common with the study of the conditions under which a modern reef is formed. The study of the conditions under which a modern reef — a reef of the present period — is formed and increases in thickness has yet to be made, and such a reef must be carefully selected. Probably a broad fringing reef resting upon a substratum readily distinguished from the reef rock, and one on which there existed a sand key close to the outer edge for boring until the substratum was encountered, would be the most suitable. But as it would be most difficult to judge from the core obtained at that or any other point where the growing reef ceased and the talus began to add to the thickness of the reef, it would be necessary to supplement this work with soundings taken close together, as well as with an examination of the bottom by dredging, either with large or small dredges or with trawls and tangles to obtain material in as many different ways as possible. Of course we can hardly expect to bring up in this way many specimens of reef building corals, but we can surely, by combining the information obtained from the nature of the soundings, the character of the bottom as shown in the larger samples secured by the dredge, and the occasional fragments of living corals we are sure to bring up, form some idea of the exact bathymetrical range to which reef building corals extend, and this is not so difficult a problem as is supposed by Professor Sollas. We should in determining this remember that in the interior of large lagoons in which there is an abundant circulation of pure sea water close to the inner edge of the outer reef flats we have very positive information as to the lower limit to which corals grow in abundance. We know that under these conditions the most flourishing belt of reef builders grows in depths of from three to eight fathoms, and beyond that the coral patches decrease very rapidly in number and size, that the patches are with increasing depth separated by wider lanes or greater areas of coral and coralline sand, or by masses of fragments of corals and of dead corals. We also know that on the sea face of the outer reef flats wherever they have been examined by means of the sounding lead, the dredge, the tangles, and the water glass, identical results have been obtained as regards the bathymetrical range of the reef growing corals, with the exception that the lower limit of depth seems to be somewhat greater, and extends in some instances to 17 or perhaps even 20 fathoms. We should also remember that there abound on all coral reefs numberless organisms whose only role seems to be to cement again the particles and fragments broken by the action of the sea or of boring animals, and they play a most important part in forming coralline limestone full of reef building corals, which yet have nothing to do with the increase of thickness of the reef from their own growth. Nullipores, Algæ, Corallines, Foraminifera, the minute fragments of corals or small particles of sand, all continue to act as great cementers at considerable depths far beyond that at which reef building corals have ceased to flourish. They act not only on the surface of the reef in the interior of the lagoons, but along its sea face and down to a considerable depth, and all along the outer slope they cement the fragments of corals which have fallen at the foot of the growing reef, and gradually transform the material of the talus into a hard limestone similar in its constitution to that of the reef building corals. But in this limestone formed of talus material, the corals no longer retain their natural attitude as when growing. It is a breccia of corals or a puddingstone, consisting sometimes of huge masses which have fallen from the growing face of the reef and rolled upon the talus along the sea slope where such a conglomerate breccia or puddingstone has been formed, and it reaches the depth of from 15 to 20 fathoms. Corals can again grow upon this buttress, and thus we may imagine the reefs of the present day to build outward and increase in thickness. This was the result which was hinted at from an examination of the sea face of the reef off Honolulu made in 1888.[1] Of course I do not deny that some reef builders may occasionally live at greater depths than those I have mentioned, but their casual occurrence at those greater depths would not materially affect the growth in height and increase in width of the great majority of coral reefs; and it is well known that Oculina, Lophohelia, and other genera, may cover extensive tracts at depths far beyond those at which so called reef builders flourish.[2]

[1] Bull. Mus. Comp. Zoöl., Vol. XVII. No. 3, April, 1889, p. 121.

[2] Pourtalès, Mem. Mus. Comp. Zoöl., Vol. II. No. 2, 1871; Wyville Thomson, Depths of the Sea, 1873, p. 432; also The Voyage of the Challenger, the Atlantic, 1877, Vol. I. pp. 266–273.

ISLANDS PARTLY VOLCANIC, AND PARTLY COMPOSED OF ELEVATED LIMESTONES.

Kimbombo.

Plates 19, 61.

The Kimbombo Islets (Plate **61**) are a group of three small islands, one, the highest, of volcanic structure; the other two, the northern islets, are composed of elevated limestone, situated in the axis of a triangularly shaped lagoon, with twelve fathoms of water. The reef flat surrounding the lagoon is continuous, except at the northwestern point, where there is a passage into the lagoon (Plate **19**). In addition to the islands there are a number of coral patches and isolated rocks along the inner edge of the reef flat and in the western part of the lagoon. The atoll is nearly five miles in its greatest length, and the southern face is about three miles long. As we did not enter this lagoon, I could not satisfy myself regarding the structure of all the outlying rocks on the outer edge of the submarine platform, some of which were evidently volcanic, others of elevated limestone. This is an interesting group, showing how varied the structure of an atoll may be, and yet the record on the chart be most deceptive, the substructure of the Kimbombos being volcanic at one extremity, and consisting of elevated limestone at the other. Half way from Kimbombo to Ngillangillah Island rises the small peak of Trigger Rock to within four fathoms of the surface; to the east of the group lies Bell Reef, to the north Williamson and Dibble's Reefs, and Lookout Reef still farther to the east, all separated by deep channels and rising abruptly from deep water. The substructure of these reefs is of course unknown, and may be either volcanic or limestone elevated or eroded to within a few fathoms of the surface.

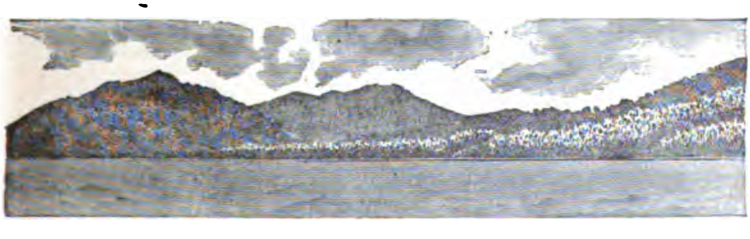
Exploring Isles.

Plates 19, 19ᵃ, Figs. 1-3, and Plates 72-76.

We entered the atoll of Vanua Mbalavu, or the Exploring Isles, as it was called by the United States Exploring Expedition in 1840, through the Ngillangillah Passage. The reef enclosing the islands is triangular in shape; its greatest length is over 22 miles along the southeastern face; the breadth from the southeastern to the northwestern horn is 20 miles. The outer reef flats are comparatively narrow, except in a few places where, near the islands of Munia, Malatta, and Susui, they pass into the fringing reef flats. There are two important passes on the southeastern face,[1] the Tongan and the American Passages. The latter is a narrow tongue of the ocean cutting into the eastern face of the slope of the atoll with over 100 fathoms in depth, and opens into a wide deep submarine valley extending westward into the heart of the eastern lagoon. The Tongan Pass is a similar, but much shallower and shorter, tongue of the ocean. On the western side the Andiwathe Pass

NORTHEAST POINT OF VANUA MBALAVU.

leads into a long deep lagoon formed by the outer reef and the west coast of Vanua Mbalavu. This western lagoon is connected on the south with the principal lagoon to the east of the island by a narrow and shallower passage over the fringing reef north of Malatta Island, and on the north by the passages leading round Ngillangillah Island into the passage of that name opening through the northwestern horn of the



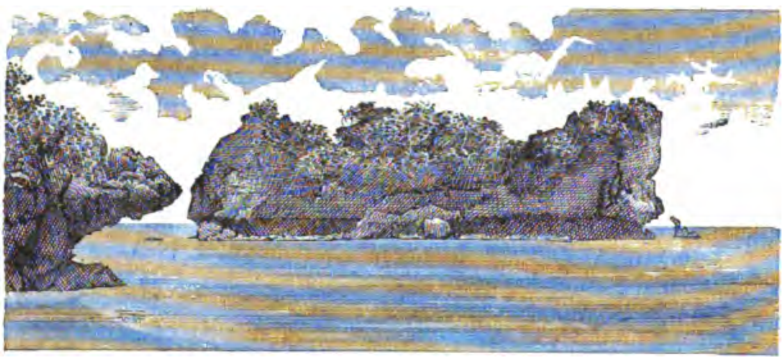
VANUA MBALAVU, LOOKING WEST.

outer reef, and which extends, gradually widening eastward, along the northern shore of Vanua Mbalavu until it opens beyond Avea Island into the large eastern lagoon. Along the northern face of the lagoon are situated Avea and Sovu Islands. About two miles from the

[1] An exception to the usual rule, that entrances to lagoons are on the lee side.

eastern face is the island of Thikombia i lau. On the southern face are Ngillangillah, then follows the principal island of the group, Vanua Mbalavu, the western shore line of which is hollowed out by a deep indentation forming the western lagoon. Off its southern extremity is situated Malatta, next Susui, and finally the volcanic island of Munia. Vanua Mbalavu is fourteen miles long, forming a sharp angle at its highest and broadest point, where the island is nearly three miles wide and reaches a height of 930 feet.

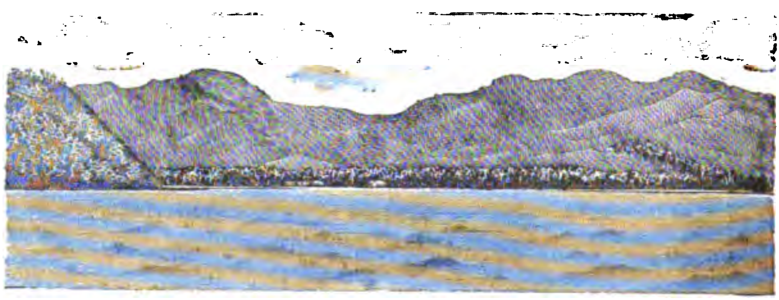
The central and highest part of Vanua Mbalavu is volcanic, but towards the northeast and the south the volcanic rocks have lifted up an ancient elevated reef which extends from opposite Avea westward. The volcanic rocks (Plate **72**) dip very rapidly to the north, so that less than half way from Koro Mbasanga to Blackswan Point the bluffs are elevated limestones. These bluffs are deeply undercut, their surface pitted and thoroughly honeycombed, and full of potholes. The extent



ISLET OFF NGILLANGILLAH.

of the wearing of this coral rock is well shown by the deep bays and numberless indentations which characterize the northern coast of Vanua Mbalavu. When we come to the vicinity of Blackswan Point, the denudation and erosion of the elevated limestone has reached its maximum. Off the end of the large island lies the little island of Ngillangillah (Plate **73**), which is entirely composed of elevated limestone, which here attains a thickness of 510 feet. Beyond Ngillangillah there are numerous negro-heads and coral patches, some of them being of considerable size; they are of ancient coral rock. The coral heads and negro-heads extend along the whole length of the outer reef flat as far as we followed it to Avea. The bluffs forming the steep sides of the island are undercut and deeply indented, forming gorges and ravines (Plate 74) which cut into the island or separate dome-like islets from the adjacent shores. The elevated limestone is full of species of coral, mainly large heads of species of Astræans, of Mæandrinas, and Pocillopores, which appear to be closely allied if not identical with those now living. One of the points of Ngillangillah was merely a thin shell covering a huge cavern some 50 feet in diameter and rising to a height of nearly 100 feet, and full of stalactites. The rock in the pool at its base was covered with Gorgonians and small corals, and abounded in Comatulæ.

The narrow channel lying between the north shore of the large island and the outer reef is full of flourishing coral patches. The many narrow deep cañons (Plate 74) cut into the face of the island with the dome-shaped or mushroom-shaped heads of elevated reef rock projecting a few feet above the water line give to this shore line a very picturesque appearance. It is a simple matter to follow the extent of the elevated reef rock eastward, and to trace the gradual appearance of the central ridge of volcanic rocks until we come to the headland north of Koro Mbasanga (Plate 72), where we find only a comparatively small outlier of the elevated limestone, and a similar one to the south of the village. Northeast of Koro Mbasanga lies the island of Avea (Plate 75), which rises to a height of 600 feet, and which is wholly composed of elevated limestone. This island as well as Susui runs at an angle from the outer reef, and shows the great width of the former elevated reef. From Koro Mbasanga south and for some distance beyond Lomaloma the volcanic rocks occupy the whole width of the island, and the elevated limestone has disappeared to reappear again on the southern spit of the main island, and to extend eastward in the islands of Malatta and of Susui and their many outliers, as heads, rocks, and islets, both on the northern and off the eastern point of the latter island. The island of Munia consists, like the central part of Vanua Mbalavu, of volcanic rocks. The island of Thikombia i lau, on the contrary, is composed of elevated limestone rising to a height of 550 feet. Beyond Avea lie the Sovu Rocks, three small islets about two miles inside the outer reef, also of elevated limestone, one of which rises to a height of 230 feet. Between Avea and the Sovu Islets runs southerly for a distance of nearly five miles a series of narrow coral patches, which, so far as I can judge, are remnants of the ancient elevated limestones, as are probably the heads and patches of the eastern part of the lagoon beyond the Tongan Pass. On the contrary, many of the heads lying off the central parts of the east coast of Vanua Mbalavu are undoubtedly of volcanic origin, and are merely covered with a thin veneer of growing corals. Some of the small volcanic rocks and islets off the east central part of the east coast of Vanua Mbalavu are deeply undercut and eroded into mushroom-shape. By far the finest example of marine erosion of volcanic rocks is seen on Plate **62**, which represents an eroded shore line with mushroom-shaped rocks off the shore, indicating a slight recent elevation. Plate **62** is taken from a photograph given us by Mr. E. G. Jones, and taken in Lau; unfortunately I am unable to state the exact locality. The islets of Yanu Yanu forming the harbor of Lomaloma consist of a yellow volcanic mud full of rounded pebbles, and some of the spits of the east coast of Vanua Mbalavu are composed of bedded volcanic mud (soapstone) similar to that found at Suva and its vicinity. The condition of the islands and islets and rocks, both of those composed of elevated coral reefs and of volcanic rock, clearly indicates the great denudation and erosion which



VOLCANIC HILLS BACK OF LOMALOMA.

have taken place, to leave only such fragmentary remains of the land which must have once occupied the area of the lagoon. It is possible that the age of the elevated limestone found at so many points in Fiji may be comparatively great, and that the ancient limestone forming the substructure of the reef of the present day may have been deposited in late tertiary times, immediately before the present epoch.[1]

As has been observed, the dip of the lagoon is to the eastward, or rather, in a general way, toward the slopes of the deep tongue of water forming the American Passage (Plate **19**). This would seem to be the natural result of the elevation of the great flat of tertiary limestones

[1] See the report of Dr. Dall, referred to in another part of this Bulletin.

occupying the area of Vanua Mbalavu Lagoon, caused by the uplifting of the ridge forming the crest of Vanua Mbalavu, which has a short western slope and a long comparatively easy eastern slope, with the resulting deep valley leading to the American Passage, and perhaps a secondary elevation caused by the rising of Munia Island.

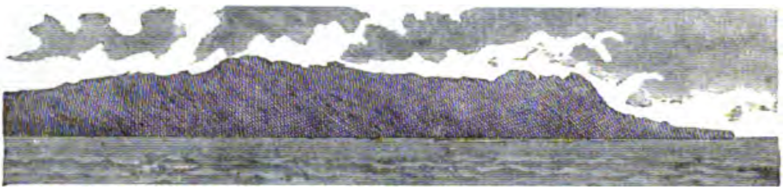
The depth of the western lagoon varies between 10 and 20 fathoms, that of the western part of the eastern lagoon from 6 to 30, while the eastern part of the lagoon slopes gradually from 20 or 25 fathoms toward the 100 fathom tongue in the eastern face of the outer reef. On sounding one mile north from the edge of the outer reef, off Blackswan Point, we found, at 203 fathoms, hard bottom. The character of the bottom of the lagoon varies greatly according to its proximity to shores or heads or patches composed of volcanic rocks or of elevated coralliferous limestone, or of a combination of both.

Nowhere in Fiji have we found the fringing corals growing in such profusion as in the Ngillangillah Channel. While steaming along the northern face of the reef, close to the outer edge, we had a good opportunity to note the appearance of the outer reef flat, of a yellowish green color covered with patches of violet, indicating the areas incrusted by living corals. Being on the lee side, there was scarcely a ripple along the outer edge, which was in sharp contrast to the very dark blue of the water covering the outer slope of the reef, while on the inner side there was a more or less wide light greenish belt bordering the reef flat and passing through light blue into the darker blue of the narrow continuation of the Ngillangillah Passage, itself dotted with greenish or yellowish patches of coral all along the reef flat, and on many of the inner patches were scattered negro-heads, consisting of elevated coralliferous limestone.

Mango.

Plates 19, 22[a], Fig. 3, and Plates 85-87.

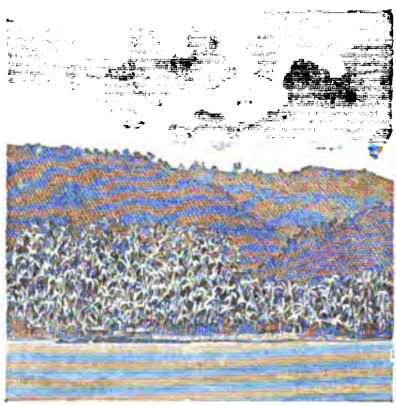
Mango is a circular island, the southeastern and southern faces of which consist of a rim of volcanic rocks, through which rises to a height of 670 feet the central elevated ridge of the island (Plate **19**). On the northern and northeastern faces an ancient coralliferous limestone has been elevated to a height of from 200 to 300 feet or more. That part of the elevated limestone which lies across the break of the rim of the island has been eroded and denuded to form a small lagoon or diminutive sound (Plate **85**). The entrance is flanked by low conical or dome-shaped mounds and patches deeply undercut, some of which are mushroom-shaped. A passage has been cut for boats through the shallow opening connecting the lagoon with the inner sound, which receives the drainage of the interior of the depressed basin. The elevated limestone bluffs extend from the northern horn of the rim, along the coast line, towards the landing place on the north face of the island. To the



MANGO, SEEN FROM THE NORTHEAST.

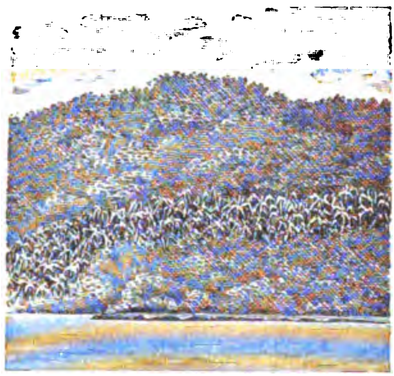
east of this, on the north shore, are fine bluffs of elevated limestone, weathered into dome-like lamellar masses, with rounded masses and mushroom-shaped heads at the base (Plate 86). A little farther west, on the beach beyond the bluffs, the underlying volcanic rocks crop out again, and from there south the negro-heads on the western reef flats are all of volcanic origin.

The island of Mango is almost circular, about three miles in diameter, surrounded by a barrier reef, which passes into a fringing reef off the northern coast near the landing, and off a part of the southeastern face of the island. The inner lagoon is very narrow, not more than a quarter of a mile in width, and also very shallow. Its greatest depth is about two fathoms, and it is further studded with negro-heads and coral patches, thus protecting the lagoon to a certain extent from the invasion of the sea. The ridge of elevated coralliferous limestones on the west side of the island extends as far as the first islet on the south face of Mango. There the central volcanic ridge which has raised the reef joins the western edge of the rim of the island. The ridge runs in a southerly direction, at a



MANGO LANDING, VOLCANIC SUBSTRATUM.

slight angle with the west coast ridge, and is separated from it by a deep valley. The three islets off the western part of the southern face of Mango are all on the outer edge of the reef flat (Plate 87). They consist of volcanic rocks. The central islet is the largest, and is composed in part of stratified volcanic mud underlaid by harder rocks. Between the islets, and extending over the outer reef flats to the north and to the east, stretch numerous negro-heads of a volcanic nature.



WEST OF MANGO LANDING, VOLCANIC SUBSTRATUM.

The island of Mango is of the same type as Fulanga, except that the erosion and denudation of the lagoon has not been carried on to so great an extent, Mango being composed so largely of harder volcanic rocks. The platform forming the reef flat is dug out into a very narrow and shallow lagoon, and both are studded with negro-heads, the remnants of the adjacent shore slopes. The inner sound, which in the case of Fulanga has been eroded and denuded to form a large inner basin, consists in Mango only of a diminutive basin studded with elevated limestone heads and rocks, and barely connecting with the exterior eastern lagoon; the sea has not found its way to any extent through the elevated limestone barrier lying across the break of the rim of the island.

Lakemba.

Plates 19, 21.

The island of Lakemba is elliptical, with a prominent spit extending off its southern face. Its greatest diameter is about five miles and a half. The central mass of the island, which rises to a height of 720 feet, is volcanic; on the flanks of this, on the northwestern and western sides, are found nearly vertical steep shore bluffs of coralliferous limestone elevated to a height of from 200 to 250 feet. The ridges extending along the south shore, separated by a spur from the central mass, also consist of elevated reef rock. Lakemba is surrounded by a fringing reef, narrowest off the northwestern point of the island; it widens towards the south off the west coast, and on the eastern face of the island it attains a width of nearly a mile. In continuation of the fringing reef off the northern face and off the southern spit of Lakemba extends a narrow outer reef, enclosing a lagoon, irregularly rectangular in shape, about five miles in length. The lagoon is thickly studded with patches and heads; its greatest depth is 14 fathoms; on the east face of the outer reef there is a passage for steamers. This is another exception of a lagoon entrance on the windward side. It should, however, be noted that the east face of the Lakemba atoll is protected to some extent by Aiwa and Oneata.

The resemblance in shape of Lakemba and Kanathea, the latter of which we did not visit, is very marked. The encircling reef of the latter surounds a larger lagoon; there is also a narrow extension of the lagoon on the south side of Kanathea, and a boat passage on the east face. One mile and a half south of Kanathea, and separated from it by a channel with a depth of 131 fathoms, lies the small summit of Morse Reef; and off the central part of the northern face of the encircling reef, Boehm Rock. At Lakemba Gardiner[1] has noticed the flat limestone hills which rise abruptly to a height of 60 to 70 feet on the west coast, the foundation being volcanic conglomerate, which forms the rest of the island. Captain Wilson states that on the reefs of the extreme south some of the islets are limestone, others volcanic, and he considers the three larger islands in the centre to be the remnants of an old crater.

Thithia.

Plate 20.

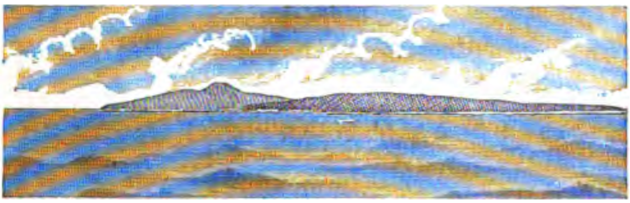
I am informed by Bishop Vidal of Levuka that the island of Thithia, which we did not visit, is also composed in part of elevated limestone, in which large caverns have been excavated similar to those we saw in Ngillangillah Island. It is also stated by others to be in part volcanic. It resembles Mango in outline, appearance, and structure, but is somewhat smaller; the fringing reef surrounding it is narrow. The central part of the island is probably a volcanic ridge, which has elevated the ancient limestone surrounding it.

[1] *Loc. cit.*, p. 466.

Naitamba.

Plate 19.

The cliffs of the southeast side of Naitamba consist of volcanic conglomerates or puddingstone, which extend along the highest points of the ridge on that side of the island. But on the northern side of the island the ridge, rising to a height of over 100 feet, is clearly seen to



NAITAMBA, FROM THE EAST.

be composed of elevated limestone. Naitamba is surrounded by a narrow lagoon (Plate 19), which is a little over half a mile wide off the north side of the island, where its greatest depth is seven fathoms. On the southwest side the lagoon is very shallow and narrow, the reef becoming practically a fringing reef. The highest point of Naitamba is 910 feet.

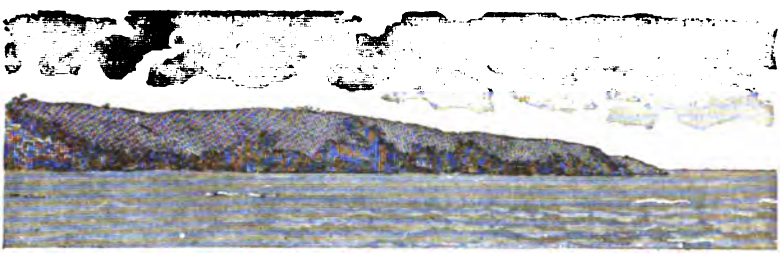
Mothe.

Plate 22.

The Mothe group is interesting, consisting of a volcanic island, Mothe, and of Karoni, a low island to the south of it, formed by a short ridge of elevated limestone rising to a height of 120 feet. An outer reef flat surrounds both the islands. It runs at a distance of a little over half a mile from the shore of Mothe itself, which is also surrounded by a very narrow fringing reef. In that part of the lagoon there is only from two to five fathoms of water, and the channel is studded with heads.

KARONI.

The lagoon enclosed by the Mothe Reef is shaped like a boot, the foot reaching towards the east and the leg in a northwesterly direction. Mothe Island is elliptical in outline. Its greatest diameter, running north and south, is about two and a half miles, and it rises to a height of 590 feet. There are only boat passages into the lagoon through the eastern face. Although these passages are on the eastern face, yet they are practically to the lee, owing to the westerly trend of the lagoon and the projection of Na Potu on the south. The deepest part of the lagoon is in the eastern point. It is only nine fathoms, and north of Karoui not more than seven. Na Potu, as the eastern point of the lagoon is



NORTHWEST POINT OF MOTHE.

called, is studded with rocks and heads. Off the northwestern point of Mothe we could distinctly see that the negro-heads rising upon the platform of the outer reef flats were of volcanic origin. Mothe resembles in shape Lakemba and Kanathea.

Kambara.

Plates 22, 22[a], Fig. 2, and Plates 77-79.

Kambara Island is elliptical, nearly five miles in length, with a greatest breadth of three (Plate **22**). It is surrounded by a rim of elevated limestone enclosing a depressed basin. The rim has an average height of between 300 and 350 feet, with steep cliffs on the sea face (Plate **77**). On the northwest face of the island, near the village of Tokalau, the elevated limestone ridge is broken through by a conical hill 470 feet high, which is of volcanic origin, and the flanks of which underlie the elevated limestone ridge resting on its sides (Plate **78**). From this makes out a flat covered with negro-heads, all of volcanic origin, and of rocks similar to those of the high hill, while on each side the flats are covered with negro-heads composed of elevated limestone; on both grow very flourishing coral patches, and both are steep to, the reef flat, passing rapidly into deep water, plainly showing that the corals have had no share in shaping either of these slopes, the one composed of volcanic rocks, the other of elevated coralliferous limestone.[1] The island is

[1] Throughout Fiji we found along the cliffs and sea face of limestone islands masses of the red earth so characteristic of the denuded limestones of the Bahamas and Bermudas, as at Kambara, Ngillangillah, Yangasá, Oneata, Ongea, and other islands.

surrounded by a fringing reef which ends beyond the northern point of the island along the base of the vertical cliffs between it and Tokalau village (Plate 78), and becomes the merest thread to the south of it for a short distance. Along the rest of the west face there is a narrow incipient lagoon studded with coral patches, with from one to two fathoms of depth in places between the outer reef and the shore.

Gardiner[1] describes the interior plateau of Kambara as being about 100 feet above the level of the sea, and that "on the plateau itself are many small hills, rising nearly to the level of the rim, with very steep walls, and some springing almost like buttresses from the rim itself," and that on this plateau there are a number of deep holes in which salt water is found and tidal influences are felt. This description corresponds with what has been observed in the æolian hill basins of the Bahamas and Bermudas, in which atmospheric agencies are at work to form the incipient sounds, and finally the great sounds or lagoons of the islands of these groups.

Gardiner[2] reports that the hills of Thikombia i ra are certainly of limestone, and at a distance appear distinctly terraced.

SUNDRY ATOLLS.

Pitman Reef.

Plate 18.

Pitman Reef is an oval atoll about a mile in greatest length. We passed within a cable's length on the west side, and could see the outer edge of the reef flat uncovered at points, and patches of corals growing upon it. The reef flat seems to be 300 to 350 yards in width. It is widest at the northern extremity. The lagoon is marked on the chart as being eighteen fathoms deep.

Motua Levu and Motua lai lai.

Plate 18.

Motua Levu and Motua lai lai are two atolls to the eastward of Lauthala reef. The former is somewhat rectangular, about two miles in length, and encloses a lagoon with a greatest depth of twenty-five fathoms. On the northwest edge boats can cross into the lagoon. The latter is nearly circular, a mile in diameter, enclosing a small lagoon.

[1] *Loc. cit.*, p. 464. [2] *Loc. cit.*, p. 462.

The yellowish reef flat is widest at its two extremities; the coral patches appear to be very flourishing, and a few large negro-heads of coral protruded upon the inner edge of the reef flat. From its diminutive size, the whole atoll can be taken in at a glance, and it forms an excellent specimen of its kind (Plate **112**), with its broad yellow reef flat edged on the outside by the white line of breakers separating it from the deep blue water, the inner edge passing from yellowish to light green, then to light blue, and finally to the darker blue of the central part of the lagoon.

Williamson Reef.

Plate 19.

We passed close to Williamson Reef, which is a somewhat rectangular reef flat widest at the eastern face. The greater part is dry at low water, and encloses a lagoon with thirteen fathoms. The greatest length of the reef is a mile and a quarter by nearly a mile at its greatest width.

Bell Reef.

Plate 19.

Bell Reef is separated from the Kimbombo cluster by a channel of nearly three quarters of a mile in width. It is irregularly triangular, with a reef flat of over half a mile in width. The reef flat of the western side is open. The sea breaks heavily on the eastern face, but there is little sea on the western face. The greatest depth in the lagoon is thirteen fathoms.

Adolphus Reef.

Plates 18, 22^a, Figs. 16, 17.

We steamed close to the eastern edge of Adolphus Reef. The outer rim is somewhat rectangular in outline, with rounded corners, and carries from one to four fathoms of water, enclosing a lagoon twenty fathoms in depth. It can be entered from the southwestern angle. We could not examine it, as the sea was breaking heavily upon it. We could, however, clearly distinguish the patches of corals growing inside of the breakers.

These atolls are excellent examples of the effects of submarine erosion upon areas of different dimensions, ranging in size from Pitman

Reef to Motua lai lai, Motua Levu, and to Adolphus Reef. They all owe their origin to the disappearance through atmospheric agencies of the peaks or ridges of greater or less heights which they represent, and to the formation of lagoons by submarine erosion, passing finally into such sunken banks as the Penguin, Alexa, and other banks discovered by Captain Field in the "Penguin," and figured in Admiralty Chart 1431 (see Plate **23**[a]). Possibly, as I have suggested in the case of the smaller atolls, the lagoons may represent the extinct craters of small volcanoes of which the rim has been planed off by the action of the sea.

We did not visit Duff Reef (Plate **18**), which, judging from the chart, presents no points of special interest or of difference, except in shape, from such atolls as Wailangilala.

Thakau Momo.

Plates 3[a]**, 12, 14, 23**[a]**, Fig. 6.**

On our way from Nairai to Moturiki Channel we examined the Horseshoe Reef (Thakau Momo) about nine miles northwest of Nairai. Owing to the high stage of the tide we did not find it awash, and could only trace the very narrow ring of the yellowish green flat upon which violet patches of corals could be seen dotted over its surface. This flat being edged on the outside by the narrow white rim of breakers, and the dark blue water of the deeper soundings on the inner edge being fringed by a narrow belt of light green passing into light blue and into the somewhat darker blue water of the central part of the lagoon.

The plan of Thakau Momo (Plate **23**[a], Fig. 6) shows the narrow rim forming the outer edge of the lagoon awash, with a depth in the centre of twelve fathoms. The western edge is worn away, leaving the greater part of the rim of the lee edge more or less open to the outflow of the water pouring in over the weather edge.

Tova Reef.

Plate 23[a]**, Fig. 5.**

The plan which is given of Tova Reef is more detailed, and shows a lagoon with a more complete rim than that of Thakau Momo, with boat passages on the lee side through the northern and western rim of the encircling reef. These two atolls are sharp peaks, the one, Thakau Momo, probably the summit of a volcanic ridge, the other, Tova, perhaps the summit of a peak of elevated coralliferous limestone, which have been denuded to the level of the sea and then subjected to submarine erosion, forming first a flat, then an incipient atoll of which the lagoon has been gouged out, in one case to twelve, in the other to sixteen fathoms. Upon the outer edge of the flats, corals have grown, protecting the rims to a great extent from further denudation and erosion.

The depth of the plateau from which Tova rises is probably very considerable. The depth of water at a distance of seven or eight miles is, judging from soundings to the eastward, perhaps as much as 1,200 or 1,500 fathoms; while Thakau Momo apparently rises from a shallower depth of less than 500 fathoms to the north, and about 900 fathoms at a distance of about five miles.

Such atolls as Thakau Momo, Tova, and a host of others occurring in Fiji, are identical in their mode of formation with such an atoll as the Hogsty in the Bahamas,[1] the lagoon of which I believe to be due to mechanical causes similar to those which have shaped the above named lagoons in Fiji. While the former are recognized by writers on coral reefs as true atolls, the latter are regarded as pseudo atolls. It is juggling with words to represent structures as different because the one is in the Pacific and the other in the Atlantic, and because the one is in an area recognized as stationary or as one of elevation, while the other is in an area formerly supposed to be one of subsidence and which is now found to be one of elevation. In both cases the coral rims of the atolls are shown to be of little thickness. The same authors refuse to recognize as true barrier reefs, and call them patch reefs, barrier reefs occurring in other districts than those examined by Dana and Darwin, because they have been shown to be of comparatively moderate thickness. We can now show, in the very districts which have been selected as typical, that neither the coral reefs of the atolls nor those of the barrier reefs have the thickness attributed to them.

Thakau Lekaleka.

Plates 21, 111.

On our way from Oneata to Mothe we steamed close to Thakau Lekaleka (Plate 21), a very narrow reef flat of polygonal outline, somewhat more than a mile in diameter, enclosing a shallow lagoon, judging from the light blue color of the impounded water. The reef flat rises

[1] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, p. 103, 1894.

on the western edge of a bank sloping to the eastward, the 100 fathom line being more than half a mile from the eastern edge of the reef flat.

A number of negro-heads, apparently coral, could be seen on the western horn of the reef flat. Plate 111 gives a good idea of the appearance of the curve of the narrow reef flat of one of these smaller atolls, with the sea breaking over the rim.

LAGOONS OF ATOLLS.

Dana denies that there is any connection between the channels of lagoons and prevailing currents, and asserts that the channels tend to be closed by the increase of growing corals. Certainly our experience in Fiji could not indicate such a conclusion, nor are the lagoons in the smaller islands without channels except where a closed ring of coral sand islets has accumulated on the outer rim, — a rare occurrence, and one where the lagoon was formed while open to the influx of the sea. Some of the small islands, with lagoons which are dry, may be elevated islands reduced to that stage by atmospheric agencies.

While there may be a large amount of coral ooze and mud deposited in the lagoon, yet even in the lagoons mentioned by Dana he states that the sea has access to them, and that they are remarkable for the salinity of the water and the absence of growing corals within the lagoon at high water.[1]

Dana says[2] that nine tenths of the atolls under six miles in length, half of those between six and twenty miles, and the majority of all atolls in the Pacific Ocean, have no entrances to the lagoon a fathom deep, and the larger part of those included in each of these groups have no open entrances at all. He further says that nine, ranging from one and a half to three miles in the larger diameter of the reef, have no lagoon, only a small depression in its place; two of these take in water at high tide and the rest are dry (namely, seven), certainly a very small proportion, and that of diminutive atolls which give us little information regarding the formation of the larger ones. Surely we cannot reverse the process and let the formation of the large atolls precede that of the smaller, as is suggested by Dana,[3] for in that case we should have around the small atolls the platforms or slopes which have gradually been formed by the filling of the larger lagoon as sup-

[1] Dana, Corals and Coral Islands, p. 182.
[2] *Loc. cit.*, p. 300. [3] *Loc. cit.*, p. 302.

posed by him, and I know of no small atoll in which any such platform has been observed.

Neither Dana nor Lendenfeld seem to take into account the mass of water which is poured into a lagoon, even if it has no boat passage, over the reef flat at low tide, to say nothing of the period during which the reef remains covered between low and high water times.

A large atoll, like that of Ngele Levu, if it has been formed by subsidence, should be of greater depth. This has already been noticed by Admiral Wharton.[1] Ngele Levu is thirty-three miles round, gradually increasing in depth towards the western extremity from four to sixteen fathoms. It rises gradually from a ridge with a depth of about 145 fathoms, and from a plateau of less than 400 fathoms in depth. There is no filling up of that lagoon; it is well scoured, and a strong current is constantly deepening the entrance and outlets at the western end, to say nothing of the mass of water which finds its way out over the reef flat. The lagoon of an atoll is often referred to by writers on coral reefs as a sort of stagnant pool, which must of necessity be gradually filling. Such is certainly not the case in the atolls with which I am acquainted, and it is the exception. If any one will take the trouble to examine the hydrographic charts of the coral reef regions, both in the Pacific and the Atlantic, they will find it to be the exception when the atoll of a lagoon is really impounded, or that of a barrier reef is shut out from a most active circulation carried on by the breakers rolling over the rim of the one and the barrier of the other into the enclosed lagoon. In Fiji, the only atolls which are enclosed and surrounded by a reef allowing no circulation or access to the sea are small, and play no part in the physiognomy of the reefs of the group, and I know of no barrier reef in Fiji the lagoon of which is not well threshed by the breakers.

An examination of the charts accompanying this report will show on the rim of the larger atolls, both to windward and leeward, moderate depths, from one to three fathoms or less at innumerable places, forming a regular sieve of passages through which the breakers force their way. An examination of the charts will show the same results as regards the circulation across the barrier reefs of Fiji. Finally, we should remember that at high tide even fringing reefs are washed in every part and scoured, and that, while at low tide a certain amount of stagnation in pools may occur, it is only temporary, and not the natural state of things.

[1] Nature, May 22, 1890, p. 81.

Lendenfeld [1] gives altogether too great prominence to the part played by dry atolls. They do not occur anywhere except as most diminutive atolls. The only atoll in Fiji which answers at all to the theoretic requisitions of Lendenfeld is that of Vuata Vatoa (Plate **23**ᵃ, Fig. 4), near Turtle Island, in Lau. I have not visited the island, and my impression is taken from the chart [2] and the Sailing Directions where it is described. Yet even that atoll has outfalls on the northwest side, and the margin is awash at high water, evidently allowing large masses of water to be poured into the lagoon, so that further denudation and erosion must eventually so modify this atoll that there will be a larger and more open lagoon than formerly, and it will not fill up as is required from the other point of view.

EXTINCT CRATERS AND ATOLLS.

There is, however, still another phase in the formation of atolls which has received but little attention, and that is the influence of the denudation and erosion of volcanic summits or ridges, or of extinct craters, in the formation of atolls. There are in the Fijis two extinct craters which are most interesting. One of these is the small extinct crater of Thombia in the Ringgold Islands (Plates **18**, **70**). The highest point of its rim, the exterior circumference of which is nearly two miles, is nearly 600 feet, and it is continuous with the exception of a small part of its eastern edge, about a fifth of a mile, across which a coral reef extends, the extension of the fringing reef surrounding the island closing the entrance to the crater; the enclosed basin has a depth of 24 fathoms. The other extinct crater is that of the island of Totoya (Plates **16**, **22**, **66–69**), an isolated peak in the southern part of the group. It is about six miles in diameter, with an inner basin of three miles in diameter and a depth of over thirty fathoms. The highest point of the rim is 1,200 feet, and at two points the rim is low, forming in one case a narrow isthmus separating the crater basin from the outer lagoon. The horns of the open rim are connected by a coral reef, over which thunders the Pacific swell, piling up the water into the great basin of the crater. This water finds its way out through an opening called the Gullet, which, though narrow, forms an excellent passage into the anchorage inside of the crater. This island has not only a fringing

[1] Nature, June 12, 1890, p. 148.
[2] Admiralty Chart, Plan 742.

reef, but also a barrier reef of a triangular shape surrounding it. It is evident that this barrier has been formed upon the denuded and eroded spurs of Totoya, which once extended seaward from the outer rim of the volcano.

Supposing, now, that the erosion of both Thombia and Totoya had continued for a period of time long enough to have reduced the rims of these volcanoes to the level of the sea, we should have, as soon as corals had covered the flats thus formed indicating the former existence of the rim, atolls of nearly circular form; the one with a circumference of only two miles, and a depth of 24 fathoms, without patches in the central lagoon; the other much larger, more than 25 miles in circumference, having a depth of 34 fathoms inside the lagoon, which would be dotted with patches, some of them forming part of the rim, others being the remains of eroded spurs extending towards the centre of the extinct crater.

Admiral Wharton[1] has given a most interesting sketch of Clipperton Atoll, in which he confirms the trachytic nature of the "Rock" of Clip-

CLIPPERTON ROCK.
(From a Photograph by J. T. Arundel.)

perton, as determined by Professor Wolff[2] from specimens collected by Mr. Jensen and kindly sent me by Professor Davidson. The photographs and specimens collected by Mr. J. T. Arundel, on which Admiral Wharton's notice is based, have enabled him to give what seems to me a natural explanation of the character of the atoll. As he says, it is

[1] Quart. Journ. Geol. Soc. of London, May, 1898, p. 228.
[2] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, p. 174, 1894.

"the rare case of coral forming on the lip of a volcanic crater, one part of which alone, perhaps the plug, has resisted the action of the sea, which has worn the rest of it down to the limits of wave action." The foregoing figure is a view of the rock (trachytic) rising to a height of sixty-two feet on the rim of the atoll. Admiral Wharton calls attention to the great depth of this lagoon, perhaps fifty fathoms, as a depth not improbable if it be the crater of an extinct volcano. It would be most interesting to have Clipperton carefully examined and mapped. In the mean time, from its analogy with Totoya and Thombia, it seems to me that Admiral Wharton's explanation is the only possible one. We may perhaps add that the old rim may have also been subject to atmospheric denudation and erosion, in addition to being blown away in part during some eruption.

There are in the Fijis a number of small atolls from one to three or more miles in circumference, the formation of which can also be satisfactorily explained on the theory that they have been formed upon the eroded summits of extinct craters, reducing the rim of the volcano either to a continuous flat or to flats separated by deeper passages, as in the case of the low parts of the rim of Totoya, forming entrances into the enclosed lagoons. Such atolls are Motua Levu, Motua lai lai, the Adolphus Reef (Plate **18**), Bell Reef, Pitman Reef, Williamson Reef (Plate **19**), Horseshoe Reef (Plate **14**), and Thakau Lekaleka (Plate **27**), although it is possible that some of these atolls may have been formed from the submarine erosion and denudation of volcanic peaks or of elevated limestone masses. It is also possible that some of the larger groups in which volcanic islands are found, like Vanua Mbalavu (Plate **19**), Komo, Mothe (Plate **22**), Lakemba (Plate **21**), and Mbengha (Plate **8**), may represent parts of the rims of extinct craters, the bulk of the volcanic peaks having disappeared from erosion, and left the outer flats upon which the barrier reefs have grown, while the deeper valleys and gorges of these volcanic islands represent the undulations of the lagoons, which vary greatly in depth, reaching in the case of the Vanua Mbalavu (Plate **19**) 72 fathoms in parts of the eastern slope of the lagoon. These great depths, far beyond any at which corals can grow, represent the elevated gorges of the slopes of the volcanic peak which probably once extended over the whole area enclosed by the outer reef, during the elevation of which the reef which once covered a part of the same area was lifted to its present or even a greater height.

Such large volcanic centres with extensive craters of considerable depths are not unknown.. Haleakala (Plate **71**) in the Sandwich

Islands has a crater with a depth of nearly 450 fathoms, while many smaller peaks, some of fully 1,200 feet rise from its bottom, and its diameter is fully as great as that of many of the larger atolls of the Fijis. So that, at any rate in a volcanic district, the great depth of some of the atolls cannot now be considered as a proof of the theory of subsidence.

A still larger extinct crater than Haleakala is that of Aso San in Japan, and in Java there are many craters of dimensions fully equal to those of a number of Fiji atolls.

In addition to Thombia and Totoya, we found at Moala the rim of an extinct crater forming the deep bay on the east side of the island (Plates **16, 56**). The longest diameter of this crater must have been fully three miles, and had the denudation of the island been carried on somewhat further, so as to eat away the low western rim of the crater (Plate **56**) and connect the deep bay of the east face (the extinct crater) with the indentation on the west of the island, it would be difficult to detect the existence of a former extinct crater from the narrow ridge or island which would rise in the eastern part of the lagoon (Plates **16, 56**).

Krämer[1] has attempted to account for the elongated outline of so many of the atolls of the Paumotu, Caroline, Marshall, Gilbert, and Ellice Islands, upon the theory that they owe their origin to submarine hot springs and volcanic eruptions, the material of which was distributed by the trend of the great oceanic currents in the general directions indicated by these island groups.

While granting that volcanic agencies have raised the coral islands of the Pacific, we must remember that the shape of the islands and their extent are due to the size of the plateaus of submarine erosion which form the banks upon which coral reefs have grown. Undoubtedly the substratum of many of the atolls may have been formed of volcanic ashes by eruptions similar to that which has thrown up Falcon Island, and which has been fully described by Lister.[2] Yet the great majority of the vol-

[1] Bau d. Korallenriffe, p. 88.

[2] J. J. Lister, A Visit to the newly emerged Falcon Island, Tonga Group, South Pacific. Proc. Roy. Geog. Soc., 1890, Vol. XII. p. 157.

The island (Falcon) is composed of fine-grained dark grayish material, arranged in strata. "A bare brown heap of ashes round which the great rollers break and sweep the black shore in sheets of foam." The eruption occurred four years ago; its present height is 153 feet. "Considering how rapidly the island is being covered by the action of the waves, it is evident that in a few years . . . it will have disappeared beneath the surface of the ocean. . . . Some distance to the east of it lie two islands, Namuka iki and Mango, and these islands have been elevated before any canic islands which abound in the coral reef districts of the Pacific do not consist of such easily scattered material. In addition, it is well known that many of the islands are composed of elevated coralliferous limestones, and that is probably the composition of the substratum of many of the atolls of the Paumotu, Ellice, Gilbert, Tonga, and Fiji groups. They indicate the existence of more or less extensive submarine ridges composed either of limestone or of volcanic rocks, and not necessarily peaks or summits formed of volcanic ash and spread out by the action of the currents, as has been mapped out by Krämer.[1] Nor do we know enough of the configuration of the bottom to justify the statement that the atolls of a group are not separated by great depths such as separate the islands of the Samoan group. The soundings round Funafuti by the "Penguin," and others near Tonga and in Fiji (Plate 1), do not confirm Krämer's views.

The old view entertained by Chamisso regarding the mode of origin of the substratum upon which coral reefs are built does not greatly differ from that which we have applied to the formation of coral islands in Fiji. We have laid greater stress upon denudation and submarine erosion after elevation by volcanic agencies, while Chamisso[2] accepts the uplifting of the insular masses to the level at which coral begins to grow.

considerable thickness of coral grew upon them. They are formed by stratified volcanic material deposited under water, and are now surrounded by broad coral reefs. In them we may read the possible future history of Falcon Island. If no elevation takes place, the stones and débris will give a resting place to a host of marine animals and plants, . . . and another fine island will be added to those summer seas." Recent volcanic action in Tonga and in Samoa does not seem to have prevented there the formation of extensive coral reefs, as has been suggested by Dana.

[1] *Loc. cit.*, pp. 95–97.

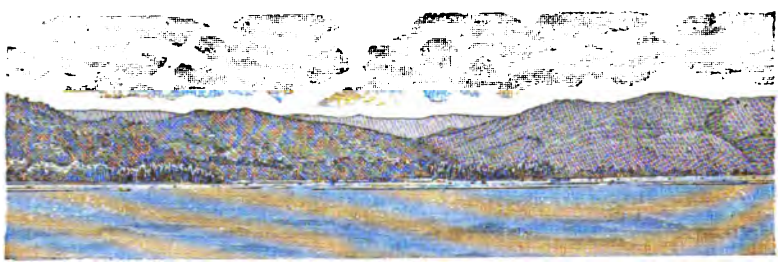
[2] "Wir denken uns eine Inselgruppe dieser Bildung als eine Felsenmasse, die sich mit senkrechten Wänden aus der unermesslichen Tiefe des Oceans erhebt und oben, nahe an dem Wasserspiegel, ein überflossenes Plateau bildet. Ein von der Natur rings um am Rande dieser Ebene aufgeführter breiter Damm, wandelt dieselbe in ein Becken um. . . . Er ist da Stellenweise unterbrochen und seine Lücken bieten oft selbst grösseren Schiffe Fahrenge dar. . . . Innerhalb dieser Thore liegen öfters einzelne Felsenbänke. . . . Andere ähnliche Bänke liegen hie und da im Innern des Becken zerstreut." Kotzebue, Reise, Bd. III., Bemerkungen und Ansichten, 1826, von Adelbert v. Chamisso, p. 106. Chamisso gives an admirable account of Radack Ralick, and of the fauna, flora, and general aspect of this low coral island.

VITI LEVU REEFS.

Plates 1, 3, 5, 6, 7, 20a, Figs. 9-12, and Plates 24-45.

The great barrier and fringing reef which follows the southern and part of the eastern coasts of Viti Levu may be said to begin off the north-eastern extremity of the island of Ovalau (Plates 3, 7). Off that island a spur of the barrier reef extends in a northerly direction, terminating in deep water (Plate 3). From that point to off Tova Peak there is no barrier reef, the bottom being generally muddy, formed from the decomposition of the islets composed of soapstone, which are scattered in great number between Ovalau Island and the island of Viti Levu. Similar islands and islets abound along the shore of Viti Levu, and between it and the outer reef south of Moturiki towards Mbau and the Tomberua Passage (Plate 7).

The islands of Viwa (Plate 36) and Mbau are both composed of stratified volcanic mud resting upon harder volcanic rocks, and the whole shore line of the adjoining part of Viti Levu is made up of the same material, judging by what we could see of the shore bluffs as we steamed

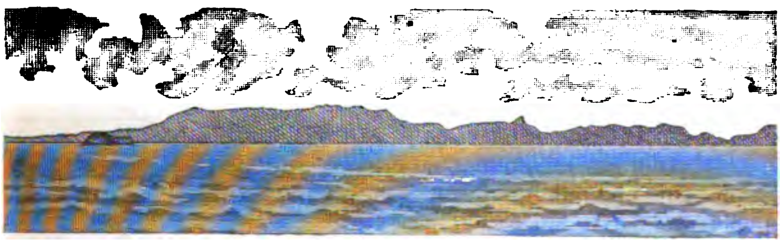


FRINGING REEF HARBOR, OFF KORO LEVU.

from the Moturiki Channel to Mbau. The soft rocks of the shores of that part of Viti Levu are readily disintegrated, and their erosion and denudation have supplied the material for the extensive mud flats (Plate 35) lying in the area just mentioned (Plate 7), leaving endless patches and small flats more or less covered with patches of growing corals. These softer rocks rest upon harder volcanic rocks, the extension of the rocks which attain a considerable height in Moturiki and a still greater one in the peaks of Ovalau.[1]

[1] Both Ovalau and Moturiki are surrounded by a fringing reef.

The formation of the great barrier reef of the southern shores of Viti Levu is due to causes very similar to those which have given its present physiognomy to the northern coast of Cuba between Nuevitas and Matanzas. Along those parts of the island where denudation and erosion proceed rapidly owing to the soft character of the shore rocks, very extensive flats have been formed like those south of Ovalau. When the reef barrier flats have been eroded from a harder base, like volcanic rocks, the flats are less prominent; they are somewhat more extensive where the old elevated coralliferous limestone formed the shore hills; or the reef flats may disappear altogether when the harder volcanic rocks have been only little affected by erosion or denudation. From the nature of the negro-heads scattered upon the reef flats it is generally a simple matter to ascertain the character of the base of the reef flats of an atoll or of a barrier reef.

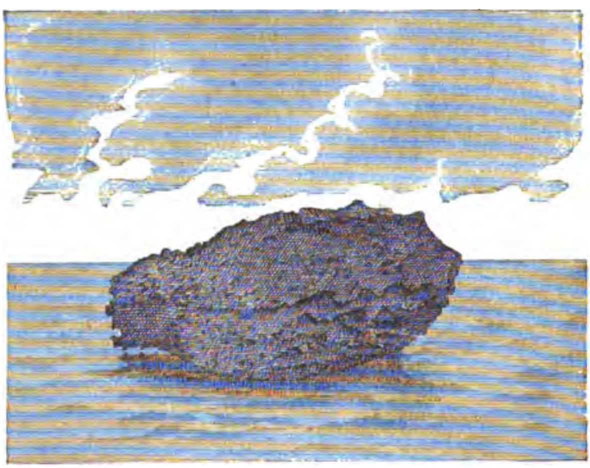


MOTURIKI CHANNEL.

The islands of Ovalau and of Moturiki (Plate 7), which are enclosed by the northeastern extremity of the Viti Levu barrier reef, are both of

ENTRANCE TO LEVUKA.

volcanic formation, a kind of conglomerate or breccia similar to that found at Mbengha, Tavuki in Kandavu, and in many other places in Fiji. The highest peak of Ovalau rises to a height of nearly 2,100 feet, and the shape of its ridges, crests, and peaks (Plates **33**, **34**) shows the effect of extensive denudation and erosion. The island is elliptical, eight miles long, and about six wide. Moturiki flanks Ovalau on the southwest side, is low, about five miles long, and connected with the southern face of Ovalau by an extensive fringing reef flat surrounding its eastern face and the islands of Yanutha Levu and Yanutha lai lai. The Moturiki fringing reef is separated from the barrier reef by a narrow channel, and the northern extension, forming the barrier reef off the east coast of Ovalau (Plate **20**[a]), is broken by a number of deep openings (Plate **7**). The bottom of the lagoon is made up of coral and coralline sand, comparatively little mud being washed down from the hill slopes, the water inside the lagoon being quite clear. From the inner edge of the barrier reef run out a large number of very flourishing coral patches in from two to three fathoms, and extending to seven or eight. The reef flat is in some places more than half a mile wide (Plate **20**[a], Figs. 1–5). A good many



NEGRO-HEAD, LEVUKA BARRIER REEF.

negro-heads are scattered upon the reef flats, some of them of considerable size. The average depth of the narrow lagoon separating Ovalau from the barrier reef is from nine to fifteen fathoms, but in some places there are short stretches with a depth of from sixteen to twenty fathoms.

Between the Na lulu and the Ngava Passages (Plate **7**) an extensive flat connects the barrier reef with Ovalau, much as the fringing reef of

Moturiki is connected with the barrier reef stretch opposite its eastern face. There is also a similar connection between the fringing reef off Bololo Point and the barrier north of Na lulu entrance. The south-eastern part of the reef off Ovalau and Moturiki being strictly neither a barrier nor a fringing reef, but a combination of the two, the Ngava and Na lulu entrances forming reef harbors similar to those characteristic of fringing reefs, indicating how the offshore platform of Ovalau has been eroded and how corals have gradually obtained a footing on the underlying volcanic substructure, remnants of which are visible at many points of the barrier reef flats. One may judge of the extent of the denudation and erosion which have taken place from the shape of the peaks and bluffs and ridges which give to Ovalau so characteristic a profile when seen from the sea (Plates **33**, **34**). Compare the sharp peak of Tumuna, the rounded elevations forming the ridge of Ndelai and of Koro Levu, the sugar loaf of Craig, and the bluffs near Levuka.

LEVUKA.

The spur which has formed the island of Moturiki is covered by low conical hills, culminating on the eastern summit at Ului Mboa, which is but little higher than the rest of the island.

To the westward and northward of Ovalau reach the extensive flats full of patches which connect the west shore of Ovalau with the mainland, and reach on the northwest to Tova and south towards Mbau (Plate **7**); flats which are formed by the disintegration of the low bluffs, consisting of bedded volcanic mud ("soapstone"), which must once have extended eastward close to Ovalau and Moturiki. The patches on the flats are covered with growing corals.

The stretch of strata of volcanic mud constituting the east shore of Viti Levu north of Mbau undoubtedly once extended farther east, connecting the main island with the islands of Moturiki and of Ovalau. This readily explains the changeable character of the barrier reef at different points along the coast of Viti Levu. Off Ovalau and Moturiki the substructure of the barrier reef is volcanic, and the negro-heads which crop out upon its surface at various points plainly indicate this. One of the most striking of these protrusions being a small mushroom-shaped volcanic rock on the barrier reef to the south of Moturiki, immediately west of Thangalai Island (Plate 7). This island and Leluvia, and one or two keys on the northern part of the great reef south of Moturiki, are small islets of coral sand thrown up on some of the shallower parts of the reef flats. The larger islands are thickly covered with cocoanuts and shrubs. On the southern part of the reef flats immediately north of the Tomberua Passage near the exterior edge is the island of Mumbualau. It is about thirty feet high, and is composed of elevated coralliferous limestone deeply undercut, pitted, and honeycombed, while the islands farther inland off Kamba Point consist of stratified volcanic mud.

Another very striking fragment of elevated coralliferous limestone is that of Na Vunivatu (Plate 37), on the reef flats to the south of Nasilai Mouth. The remnants of the elevated reef can be traced south of Tomberua Passage on the Nasilai reef flats, and extend on both sides of the lighthouse. There are numerous heads of elevated limestone, fragments of former large stretches of the same material. Still farther south the elevated coralliferous limestone is seen to underlie the island of Nukulau (Plates 38–41) at the mouth of Lauthala Harbor (Plate 25), as well as the flats to the eastward and the island of Mokaluva with its flat (Plate 38). The extensive mud flats forming the mouth of the Rewa River have to a great extent encroached upon the inner edge of the coral reef flats underlaid by the elevated coralliferous limestone which everywhere crops to the surface to the south of Tomberua Passage. As far as the Nukulau mouth of the Rewa, the reefs are in reality fringing reefs growing upon flats of elevated coralliferous limestone, intersected by deep indentations forming reef harbors. The great extent of the flats skirting the shore of Viti Levu eastward from Suva Point shows the amount of denudation and erosion to which this part of the island has been subjected (Plates 24, 25). From off Lauthala Bay (Plate 25) to Suva, the reefs are extensive barrier reef flats separated by passages leading into the channel running between the barrier and the shore (Plate 7). Some parts of the barrier flats are more than a mile wide.

The barrier reef flat north of Tomberua Passage and south of Rat Passage is in many places nearly three miles wide, with an average width of about two miles. The wide reefs of Serua and of Rovondrau Bays (Plate 5) are covered with flourishing patches of corals; what their substratum is I am unable to determine from the absence of negro-heads on the outer reef flats. Judging however from the nature of the headlands and of the rocks cropping out all along the shore between Serua and Suva, it is probably of the "soapstone,"—the bedded volcanic mud so characteristic of the shores of Viti Levu both east and west of Suva, with the exception of a small key probably of elevated limestone on the end of Rovondrau Reefs (Plate 5).

To the east of Namuka Harbor, a small reef harbor formed like the Navua and the Tongoro pass through the outer reef flats, and the elevated limestone again forms the substratum of the reef flats. The reef is here a fringing reef, which can be navigated by boats near the shore after half tide, and the outer face is covered with large negro-heads consisting of elevated coralliferous limestone. West of the entrance to Suva Harbor (Plate 5) the reef occurs in successive stretches of fringing or of barrier reef outside of fringing reefs, forming in some cases small reef harbors, like Namuka, Nanggara, Vatuloa, Navua, Serua, or, opposite the mouth of the Navua River, a large open bight, Rovondrau Bay.

The passages through the Viti Levu barrier reef and its principal reef harbors, Suva among others, are generally opposite the mouth of some river or creek, through which considerable fresh water carrying silt flows; this is especially the case of the Rewa River, which brings through its many mouths an immense amount of silt and detritus, and has formed a great delta. Both Darwin and Dana have attributed the formation of reef harbors largely to local currents, to the presence of fresh water, and to the action of silt. The bringing down of detritus, especially in the rainy season, and its deposition in channels will keep the bottom clear of corals, and thus form passages or reef harbors. The extensive reef which protects the harbor of Rewa has been formed in part by the erosion of the softer volcanic beds, and in part by the deposition of the silt brought down by the Rewa and the cutting out of a barrier channel behind the reef.

To the west of Serua the barrier reef disappears (Plates 5, 6), and the shore line is now composed of hard volcanic rocks which are not easily decomposed, or consists of the soft and easily disintegrated volcanic mud strata extending as a general thing from Mbau to Serua. Although here and there the harder rocks push out to the shore, where they are edged with a fringing reef, or we may find the remnants of the elevated coralliferous limestone, which is less easily eroded than the volcanic mud strata, as in the elevated reef in a valley to the north of Suva. This reef rises to a height of 120 feet above high water mark, and is fully fifty feet thick (Plate **31**). Its extension can be traced in outliers on the north shore of Suva Harbor and on islands composed of elevated limestone at the mouth of the inner harbor of Suva, — islands which are from sixty to ninety feet in height, and rest directly upon beds of stratified volcanic mud and capped by similar strata. On the northwest shore of the inner harbor there is a bluff of the same elevated limestone rising to about sixty feet. The continuation of the reef can be traced inland and along the shore for a considerable distance.

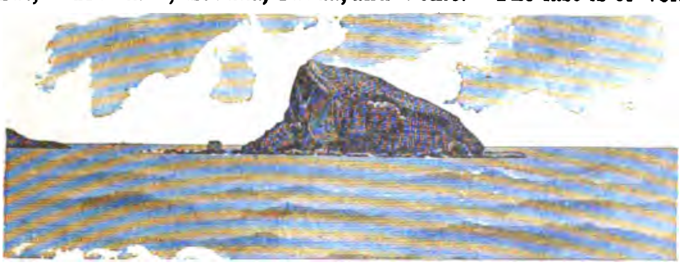
The character of the islands within the barrier reef patches of Namuka and of Serua indicate that the corals growing upon the flats rest upon beds of stratified volcanic mud (Plate **5**). Here and there we find a negro-head of the harder volcanic rock upon which the volcanic muds rest. From Serua westward the fringing reef varies in width from a mile to a mere narrow fringe of corals close to the shore (Plate **42**). Negro-heads of volcanic rock stud the reef flats, which are here and there hollowed out into small boat harbors (Plate **6**). At the Singatoka River the fringing reef has disappeared (Plate **6**), and the heavy breakers roll upon a coral sand beach for a distance of about three miles. Immediately behind the beach rises a line of huge coral sand dunes, one of which attains a height of 190 feet (Plate **44**). At this point the character of the fringing reef changes again. It is built upon the remnants of the ancient elevated limestone reef (Plate **43**), small bluffs of which occur all the way between the Singatoka River and Nandronga Harbor (Plate **45**). Some of the bluffs on the shore attain a height of more than seventy feet. Negro-heads consisting of elevated limestone fragments now abound upon the whole line of the fringing reef, and the two islands which protect the harbor of Nandronga on the east, and on the west are outliers of the ancient elevated reef (Plate **45**). The height (thickness) of that reef must have been very considerable, judging from the height of an extensive bluff, consisting of limestone to the north of the sand dunes at the mouth of the Singatoka, which must be fully 250 feet. The fringing reef extends to the west of Nandronga as far as Likuri Harbor, where it gradually passes again into a barrier reef with a gradually widening shore passage (Plate **6**) as we approach the Nandi waters.

The elevated limestone reef must have extended west as far as Viwa, and north again as far as Asawa i lau, both of which islands, as I am informed by Dr. Corney, consist of elevated limestone (Plate 2). Viwa is 100 feet in height.[1]

Plateau off Nandi and Yasawa.

To the westward of Nandi waters (Plate 3), off the northwest coast of Viti Levu, extends a wide plateau, the result of the denudation and submarine erosion of that side of the island. The depth of this plateau is most irregular, varying from ten to forty fathoms. The plateau is studded with sunken patches, and with rocks and islets and islands. The southwestern line of islands from the Mololo Islands to Mana is flanked by an outer line of reef flats, which gradually become smaller and disappear off Tartar Reef (Plate 3). From these the edge of the plateau crosses toward the north, and the outer reefs reappear again to the westward of the long chain of the Yasawa group.

The Viwa Island reef is separated by a narrow, deep channel, with 137 fathoms in mid-channel, from the western edge of the Yasawa plateau. To the northward of the Malolo Islands are scattered a few islands, — Kandavu, Lovuka, Tavua, and Vomo. The last is of volcanic



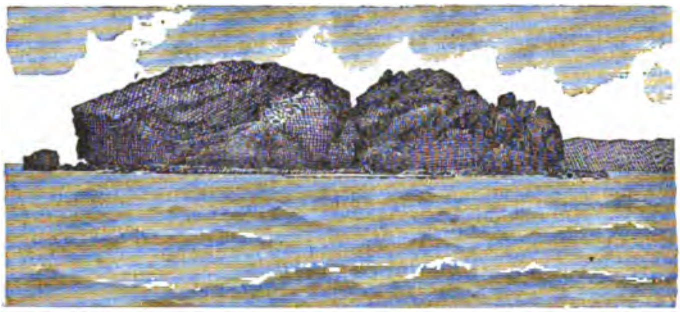
VOMO LAI LAI.

origin, while Kandavu is flanked by beach rock, as is also Tavarua at the entrance of Navula Passage. All the islands which Captain Thomson examined on his way from the Malolo Islands to Waia he found to be of volcanic origin, — Mana, Tavua, Monu, and others. As I have

[1] The elevated limestone patches which begin at Singatoka extend to the patches and reef flats north of Navula Passage (Plates 2, 3). Captain Thomson collected some pieces of a negro-head on the edge of the reef flat near Tavarua Island which consisted of elevated limestone.

already stated, Viwa and Asawa i lau are said to consist of elevated limestone.

The Malolo Islands rise to more than 700 feet. Mana is 240 feet



NORTHERN END OF MANA.

high, Mondriki and Monu respectively 590 and 730 feet, and Waia more than 1,800 feet. The extension northward of the Yasawa group forms a chain of sixteen high islands for a length of fifty miles, which terminates in the reef of the Kinsilk Islands on the south of Round Island Passage, the principal entrance through the Great Sea Reef off Vanua Levu. The Yasawa Islands, as well as the islands to the westward of the Nandi Waters, are surrounded by fringing reefs. As will be seen from the charts, the reefs are on the western face of the plateau (Plate 3); so that the outer reef flats and the chain of inner islands intercept the full access of the sea, and corals grow but sparingly inside of that line.

Suva Reef Flats.

Plates 5, 24–30, 65, 76.

Perhaps no reef flats illustrate better the grinding and wearing action of the sea than those of the barrier reef, both to the east and west of the entrance to Suva Harbor. All the inequalities of surface seem to have been levelled off as with a plane, leaving only the shallow pools formed by the interstices of the large masses of coral (Plates 28–30). The fauna of the surface of these reef flats is comparatively poor in species, but abundant in individuals. A large black Ophiothrix, with its disk hidden in some crack or corner, trails its arms in all directions, and they literally swarm in all parts of the reef. Towards the outer edge they are replaced by Echinometra lucunter, the holes and hollow ways of which, often over two inches deep, honeycomb the surface, leaving narrow walls to separate them (Plate **30**); and finally, near the outermost edge begins the belt of Madrepores and Pocillopores (Plates **28**, **29**) which extends into the line of breakers and beyond. There are few of the massive type of corals, like Porites, Astræa, and the like, and these are of diminutive size.

The surface of the reef is kept from too rapid wearing by the growth of marine algæ and of corallines which carpet it. The algæ are mainly species of Udotea, of Caulerpa, and of Turbinaria, which in sheltered pools grow to a considerable size. One finds also on the surface an occasional large black Holothurian, a blue Linckia, a green Goniaster, a Muræna darting from a pool, a large Cancer trying to hide under a shelving piece of coral, or a Squilla, or a few specimens of small fish of a brilliant blue color. There are few Mollusks under the negro-heads and dead masses of coral scattered upon the reef; the lower surface of these is often carpeted with many species of brilliantly colored Sponges, in which small Mollusks, Crustacea, and Annelids find refuge. The coral masses themselves are perforated in all directions by boring Mollusks and Annelids.

The substratum of the eastern and the western reef is made up of elevated limestone, extending from the shore close to the outer edge of the reef, independently of the thin crust of corals which grows upon the outer edge of the reef flat. So it is also with the mushroom-shaped heads which are found upon the outer edge of the reef flats of Vatu Leile, Mango, and other islands consisting wholly or in part of older limestones. They are all composed of the same rock as that of the shores and of the substructure. The outer sea face of the reef flats is steep in all cases, irrespective of the increase due to the corals growing upon them, or of the character of the underlying rock, which is only an unimportant factor in determining the thickness of the sea face edge of the outer reef flats.

We also examined the outer face of the barrier reef forming the eastern edge of the passage leading into Suva Harbor. This reef flat, like that of the western side of the passage, is entirely made up of ancient elevated limestone planed down by the sea to a level flat, with small shallow pools scattered over the surface. Negro-heads and fragments of the ancient limestone are scattered over considerable areas on the reef flat; many of them have been thrown up by the sea from the undermining of the outer edge, others have been torn off from the reef flat itself, and both are gradually wearing away, leaving fragments of branches of corals and of coral heads scattered over the reef. The belt of the reef flat close to the line of breakers is riddled with holes and channels gouged out by the Echinometra common on the reef. These channels look like short winding drill holes extending in all directions, or merely small potholes in which the Echinometræ live protected from the action of the breakers (Plate 30). In the same belt corals begin to grow in greater profusion, mainly Pocillopores, Madrepores, and small heads of Astræans and of Goniastræans or Mæandrinas, a few of these are also found scattered on the inner part of the reef flat. The corals living upon the outer edge of the reef flat form merely a thin crust, between the patches of which the substratum of elevated limestone crops out. Similarly, at a great many other points in Fiji, the outer edge of the reef flat, when exposed at the very lowest stages of tide, is seen to be edged with a belt of rocks identical in structure to that which forms the substratum of the reef flat platform. I may mention Mango, Vatu Leile, and a number of the islands of Fiji which have been described. The slope of the outer edge of the reef flat falling off more or less rapidly has little to do with the recent reef crust growing upon it; that only modifies its slope, possibly to twenty fathoms. The general slope of the sea face of the reef is due to conditions which antedate the formation of the coral reefs of the present day.

Dana[1] says that beneath the channels (basins) lies in general the coral rock of the reef region, the inferior part of the great reef formation, whose upper portions constitute the so called barrier and fringing reefs. This certainly is not generally the case: see the description of the flats between Ovalau and Mbau. Dana himself cites a number of examples which do not accord with his views when describing great admixtures of coral and of material derived from the mountains adjoining, and as he well says: "When the materials from both sources, the shore and the reef, are mingled, the proportion will necessarily depend on the proximity to the mouths of streams, the breadth of the inner waters or channels, and the direction and force of the currents."

As has already been observed by Dana, "At low tide the breakers often cease, or nearly so."[2] It is frequently possible a short time before the turn of the tide to examine the corals growing on the outer face of a reef. At Komo we had an opportunity to photograph coral reef flats where the corals were growing upon a substratum of volcanic rocks (Plate 65) just as they are growing upon a basement of tertiary limestone at the entrance of Suva Harbor. At Ngillangillah we came upon

[1] Corals and Coral Islands, p. 149.

[2] *Loc. cit.*, p. 131.

a fringing reef flat covered with Alcyonarians (Plate 76), similar to those figured by Kent.

Gardiner[1] has observed the important part which incrusting coralline algæ perform in Fiji in supplying the material for a reef rock of compact homogeneous structure; they undoubtedly assist materially in preventing the disintegration of dead corals, and their subsequent comminution by the action of the waves. In an interesting article on the calcareous algæ of the Gulf of Naples,[2] Walther has given an excellent account of the part which coralline algæ like Lithothamnium play in building up amorphous limestone deposits of considerable thickness from the obliteration of its structure.[3] But he has confused the theory of the formation of reefs with the theory of the formation of limestone deposits of great thickness, one of which is based on an assumption, the other which is not in the least open to doubt. It is evident, however, that those who have examined coral reefs have not attributed to coralline algæ the share which they have in building up recent amorphous limestone deposits of considerable thickness.

The following list of algæ collected I owe to the kindness of Professor Farlow: Amphiroa fragilissima Lam'x; Galaxaura fragilis Lam'x, var. fastigiata Decaisne; Liagora Preissii Louder, var. pacifica Grunow; Padina Pavonia (L.) Gaillon; Dictyata ciliata J. Ag. sterile; Turbinaria conoides Kg.; Hydroelathrus cancellatus Borg.; Sphacelaria furcigera Kg. ? sterile; Caulerpa Freycenetii C. Ag.; C. clavifera (Turn.) C. Ag.; C. complanata J. Ag.; Halimeda macroloba Decaisne; H. Opuntia (L.) Lam'x; H. polydactylis J. Ag.;. Aurainvillea comosa (Harv.) Murray & Boodle; Aur. papuana Murray & Boodle; Dictyosphæria favulosa Decaisne; Valonia ægagropila (Roth) J. Ag.; Valonia utricularis J. Ag.

ISLANDS AND CORAL REEFS DESCRIBED FROM THE CHARTS.

With the exception of the Argo Reefs (Plates 19, 20), the islands and reefs we did not visit were insignificant in size, or, judging from the charts, presented no point of interest not included in those we examined. I may mention among these Vanua Vatu (Plate 21), a small circular island with a depressed central summit, about a mile and a half long. It is composed of elevated coralliferous limestone rising to 310

[1] *Loc. cit.*, p. 477.

[2] Zeitsch. d. deutschen geol. Gesell., Heft 2, Bd. XXXVII., 1885, p. 329.

[3] See also an article by Fresh, Neues Jahrbuch f. Mineral., 1892, II. 169.

feet. It resembles Naiau on a smaller scale. It is surrounded as is Tuvuthá by a narrow outer reef flat, becoming a fringing reef at several points of the shore, and enclosing a narrow and shallow lagoon full of rocks and patches.

There are also a number of atolls presenting no special features. To the westward of Ngele Levu are two reefs, Thakau Vutho Vutho and Thakau Mata Thuthu (Plate 17). The former is separated from Ngele Levu by a channel eight miles wide, with 145 fathoms in mid-channel. The latter is separated from Thakau Vutho Vutho by a channel 171 fathoms deep and three miles wide. The lagoons have respectively a greatest depth of 15 and 19 fathoms. They both have navigable entrances, and the outer reef flats are studded with negro-heads and coral patches, and there are no islands on the rim. These atolls resemble Ngele Levu, but are not more than one third of its size.

It is interesting to note that to the westward of Thakau Mata Thuthu (Plate 17) there is an isolated bank with 74 and 76 fathoms of water, but separated from it by a narrow channel; it may be a spur of the bank upon which the atoll of Thakau Mata Thuthu is situated, similar to Cock's Bank, which is close to the southwestern edge of the 100 fathom line.

Similar atolls and varying greatly in shape are Duff's Reef (Plate 18) to the west of Wailangilala, and to the south Dibble's Reef (Plate 19), to the east of Vanua Mbalavu, Nuku Thikombia (Plate 19), and Malevuvu Reef (Plate 19); farther south Thakau Tambu, Yaroua, and the smaller reefs Thakau Nokeva and Thakau Lasemarawa (Plate 20). As we steamed from Tuvuthá to Naiau we saw the sandbank in the centre of Tavanuku i vanua Reef surrounded by a fringing reef somewhat more than a third of a mile in width (Plate 20). To the southwest of Tuvuthá is also situated a small circular atoll, Tavanuku i wai, with an outer reef of about half a mile in diameter enclosing a small shallow lagoon.

To the east of Mothe are Thakau Motu (Plate 22), a large atoll open to the west, with 24 fathoms in the deepest part of the lagoon (Plate 23ª, Fig. 6), and Thakau Vau (Plate 22), a small circular reef with a shallow lagoon of impounded water. Neither of these did we visit. West of Komo, Thakau Vuite (Plate 22), in a line running north and south, east of the Yangasá cluster, lies Thakau Levu, and southwest of Vanua Vatu and to the northeast of Totoya the Tova or Na Vatu Reef (Plate 23ª, Fig. 5, and Plate 20ª, Figs. 13, 14). Tova has been well surveyed (Plate 20ª, Figs. 13, 14, and Plate 23ª, Fig. 5); unfortunately we were not able to visit it, but, as will be seen, it closely resembles the Horseshoe Reef (Thakau Momo, Plate 23ᵃ, Fig. 6), which we examined. All these islands are atolls with an outer reef flat and a lagoon of moderate depth, varying from ten to about twenty fathoms as the greatest depth, with entrances into the lagoon, and with only rocks and patches and no islands on the outer reef flats.

Thakau Vau, Thakau Lasemarawa (Plate 20), and Thakau Nawa enclose impounded water. South of Thakau Levu (Plate 22) are Thakau Thikondua, Thakau Reivareiva, Thakau Nasokesoke, and Thakau Teteika, representing probably as well as Wilkes Reef north of Namuka, and the two reefs Tavanuku i wai and Tavanuku i vanua and Frost Reef, the summits of small peaks or of crests, now covered only by heads on which corals have found a footing. In the case of Tavunasithi (Plate 22), Nuku Songea, Yaroua, Maafu Rock, and the Nukutolu Islets west of Yathata, the summits are still visible. Naiabo Islet is the remnant of a small island now surrounded by a very narrow outer reef flat enclosing a lagoon.

We did not visit the Nukutolu Islets (Plate 19), which seem to be the summits of a former narrow ridge. Frost Reef, to the west of Mango (Plate 19), is a flat circular reef of about a mile in diameter, with a rock at its northern edge.

Neither did we examine the following islands and reefs to the south of the Exploring Isles (Plate 19): Malevuvu Reef, an atoll nearly three miles long by half that in width, and a lagoon with thirteen fathoms greatest depth, accessible to boats on the west side; Katavanga, a small island, consisting, according to Captain Cocks, of elevated coralliferous limestone rising to a height of 180 feet, situated in the western part of the elliptical lagoon encircled by a reef flat widest at the eastern face, and over three miles in greatest diameter, with a greatest depth of thirteen fathoms, and an opening for small vessels on the northern side of the lagoon; and Vekai, an elevated limestone rock nearly thirty feet high on the inner edge of a circular reef about two miles in diameter, with a boat passage on the northwest side leading into a lagoon with a greatest depth of eighteen fathoms. The Malima Reef resembles Kimbombo Reef. The islets are near the centre of a lagoon about two miles in diameter.

It would not be difficult in most cases to determine how these smaller reefs have been formed. They are either in part volcanic and in part elevated coralliferous limestone, or wholly volcanic, or elevated limestone alone. The result would in either case be the same. The volcanic islets disintegrating more slowly than the tertiary limestone, it is probable that the reefs, which show no signs of volcanic rocks, have a substratum of ancient limestone of greater or less thickness, according to the height to which the particular reef has been elevated.

An atoll formed from the disintegration, erosion, and denudation of an island of volcanic structure, like Komo, for instance, would not differ in structure from an atoll like Oneata, formed from the disintegration of an island composed of elevated coralliferous limestone; but their origin would at once be detected, if the islands had disappeared, from the existence in one case of negro-heads and rocks of volcanic origin, in the other of coralliferous limestone scattered within the lagoon and on the surface of the outer reef flats. The steep slopes of these two lagoons, of different geological structure, being in no way due to the thin veneer of coral patches growing upon their respective flats and slopes, but to the fact that they are a continuation of the slopes of the islands once covering the areas of Komo and of Oneata Islands, which have been elevated and since their elevation have disappeared in great part, and have been denuded and eroded to form the platform surrounding the islands now remaining to attest their former greater extent. The denudation and erosion of these islands, being accompanied by the scouring out of the lagoons from the submarine platform through the action of the sea, caused by the incessant pouring into the lagoon of a mass of water which can only find its way out through the entrances into the lagoon or over the reef flats, where it passes out with considerable velocity, a velocity obtained in part from the hydraulic head, and in great part also from the drift due to the constant driving of the trade winds in a westerly direction.

North of the Exploring Isles there are some small banks, in from eight to twelve fathoms least water. They are Alacrity, Jeffreys, and Lewis Banks. Reid Reef (Plate **20**, **20**ᵃ, Figs. 1–4) is a narrow encircling reef, enclosing a large lagoon with three islets, rising respectively to a height of sixty, ten, and twenty feet, probably of elevated limestone. The outer reef flat is narrow on the western side, bordered by a belt of heads along the inner edge. There are two passages into the lagoon on the western face. The length of the lagoon is about eight miles, and its width five. The greatest depth is twenty fathoms.

Mbukata tanoa or Argo Reefs.

Plates 20, 20ᵃ, Figs. 5–8, and Plate 21.

These reefs are irregularly triangular, about twenty miles in greatest length. A narrow continuous outer reef flat extends along the eastern and southern faces, but the western and northern faces are bordered by disconnected reef patches (Plate **21**), and towards the northeastern face from the central part in from twenty fathoms the lagoon slopes gradually to the 100 fathom line. The western part of the lagoon is full of separate patches and clusters of rocks and coral patches. Off the west face lie two small banks, one of which is awash, the other with two fathoms of least water and covered with heads. Off the east face are three similar small banks, all of which probably represent the remnants of isolated peaks or spurs of the former land covering the Argo Lagoon. The Argo Reef is separated from the Vanua Masi (Plates **21**, **22**) atoll by a narrow channel with a depth of 115 fathoms.

The island of Vanua Masi is not quite half a mile long, eighty feet high, and is composed of elevated coralliferous limestone. Bacon Islet, sixty feet in height, is stated to be of volcanic origin; it lies on the eastern face of the narrow outer reef flat facing the lagoon. This is open on the southwest, where the lagoon is studded with heads and coral patches. The greatest depth of the lagoon of Vanua Masi is twenty fathoms, the average from twelve to sixteen. The southern part of the lagoon of Argo Reef has a depth of thirty-four fathoms, and an average depth of from twenty to thirty.

We may look upon the Argo Reef (including Vanua Masi) as vastly more denuded and eroded than that of Vanua Mbalavu, which it resembles in many respects. The islands which probably once covered the whole area of the Argo Reefs have been disintegrated, and there remain of them only the islets in Vanua Masi and the innumerable heads and patches which stud the slope of the Argo Reefs. The slope of the Argo Reefs corresponds to that of Vanua Mbalavu, and represents the slope of the volcanic island which thrust up the elevated limestones now eroded which once covered the great part of the Argo Reef Lagoon as at Vanua Mbalavu. The great open stretch on the northern face of the Argo Reefs represents a tongue of the ocean which encroached upon the northern slope of the land and has left in the shallower parts only heads and patches of corals, while in the deeper parts corals have not obtained a footing.

Thikombia.

Plate 17.

We did not visit Thikombia, the northernmost island of the group, which I am informed is composed in part of elevated coralliferous limestone rising to a height of four hundred feet. The island is a narrow undulating elongated ridge with conspicuous summits (volcanic?), one of which is over six hundred feet high; it is a little over six miles in length, and situated at the northwestern extremity of an elongated plateau extending fifteen miles in a southeasterly direction, with an average depth of thirty to over forty fathoms. The western extremity of Thikombia, as well as the southern half of the island, is bordered by a fringing reef, which extends in a long spit made up of patches and detached rocks for two and a half miles in a southeasterly direction. Gardiner states that parts of Thikombia are terraced.

Ono i lau.

Plate 17ª, Figs. 13-16, and Plate 23ª, Figs. 1-4.

We did not visit the islands to the south of Ongea. Among them are the Ono i lau Islands (Plate **1**), of which some are volcanic and others composed of elevated coralliferous limestone, the highest island being 370 feet high. These islands are surrounded by an outer reef flat, elliptical in outline, about seven miles by four, which is dotted with islets, rocks, and coral patches. To the south of these islands are the small islands of Tuvana i tholo and Tuvana i ra (Plate **17ª**, Fig. 13, and Plate **23ª**, Fig. 27), situated on the northern edges of the circular barrier reef which surrounds them. To the southwest of the Ono cluster lies Vuata Ono (Plate **17ª**, Fig. 14, and Plate **23ª**,Fig. 3), an oblong reef nearly three miles long and always awash. Turtle Island to the northeast of Ono is a narrow ridge of elevated limestone, rising to over two hundred feet, with a barrier reef about four miles long off the west face, enclosing a narrow lagoon with six fathoms of water and passing into a barrier reef on the east face. Vuata Vatoa (Plate **23ª**, Fig. 4) is a detached reef somewhat over two miles in its greatest length, enclosing a tidal basin into which there is a boat passage through the reef. This reef lies about two miles to the south of Vatoa, with two hundred and forty-six fathoms in mid-channel. Vatoa and Vuata Vatoa are probably the summits of a short ridge. The presence of elevated coralliferous limestone in this part of Fiji shows that the area of elevation of the group extended to the southernmost islands.

Viti Levu and Vanua Levu.

Plates 3, 3ª, 4, 18.

Although there are large stretches of the shores of Viti Levu and of Vanua Levu (Plates **3**, **3ª**, **4**) which I have not examined, we may perhaps assume from the information I have gathered and from an examination of the charts, that neither they nor the smaller islands and reefs in the Lau Archipelago, which have been passed by, present any features which are likely to throw much additional light on the results obtained from the examination made by the "Yaralla." The area between the Yasawa group and the north shore of Viti Levu (Plate 3) has not been systematically surveyed. All we know is that it is full of coral patches, undoubtedly the eastern extension of the patches to the northwest of Nandi waters towards the Yasawa group. How far west of Charybdis Reef the extension of the deep water bay north of Vatu i ra Channel reaches is not known. Its northern and eastern limits off Vanua Levu are well defined on the charts (Plate 3). It is interesting to note that a very steep slope — fully as steep as any of the sea faces off the reefs or smaller islands of Fiji, or as steep as the sea faces of the great barrier reef off the south coast of Viti Levu — runs off the west side of Vanua Levu from the Makongai Channel beyond Yendua Island (Plate 3), and off the east side of Viti Levu from the horn of the reef north of Ovalau to opposite Charybdis Reef. Yet on this steep face the corals form only scattered patches over the surface of the flats, extending between the shore lines toward the 100 fathom line, — patches and stretches which are separated by wide areas in which the bottom is full of heads of rocks similar to those of the adjoining shores.

Charybdis Reef and the extensive reef on the southwest side of Vatu i ra Channel (Vatu i ra Reef), represent probably the eroded summits of a more or less circular island and of an elongated ridge, on the outer edges of which coral patches have found a footing, and of which Vatu i ra Islet (one hundred feet high) is the only remnant. The lagoon varies in depth from twenty-two to twenty-seven fathoms, "with several passages into it through which the tide runs strongly." Charybdis Lagoon is full of rocks and patches its average depth is about twenty fathoms; its western edge is open, with rocks scattered along its face.

An extensive fringing reef skirts the north shore of Viti Levu, which disappears within reach of the influence of Ba River. There is a wide navigable channel between it and the broad outer barrier reef patches, which resemble those off the east coast of Viti Levu, south of Moturiki Channel.

I have not examined the shores of Vanua Levu, but according to Horne[1] and from some verbal information relating to the barrier

[1] John Horne, "A Year in Fiji," London, 1881, pp. 167, 168. Horne says that on the southwest side of Rambe a reef has been elevated twenty feet, and that the

reef, its character is similar to that of Viti Levu, the substratum of the reef flats being either hard volcanic rocks, or stratified volcanic mud, or remnants of elevated limestone. The northern shore of Vanua Levu from Cape Undu (Plate 4) west is flanked by wide extensive stretches of barrier reef patches; between them and the shore exists a broad navigable channel full of islands and islets, and the whole of the shore is also indented by deep bays separated by prominent promontories almost isolated from the larger island; plainly indicating that the flats and patches occupy areas formerly covered by large islands or by former slopes of spurs from Vanua Levu itself, which have been eroded and denuded and separated from the larger island. The outer flats and patches of the barrier reef, which as it extends westward beyond the Mali Passage forms the Great Sea Reef, and is nearly thirty miles distant off the western point of Vanua Levu. The islands and islets off the north coast of Vanua Levu form a broad belt of islands separated by islets, rocks, and patches; on the western extremity of the belt is Yendua Island and the islets extending westward.

The existence of fringing reefs inside of barrier reefs is a very striking feature of the Fiji coral islands. Their absence in some localities has been explained by Dana [1] on the supposition that the conditions are more favorable to the growth of corals on a barrier than on an interior fringing reef. Yet in some of the wide lagoons of Fiji the corals of the fringing reef grow quite as luxuriantly and to the same depth as those on the outer edge of the barrier reef, and are often more abundant than those of the lagoon slope of the barrier reef. Depths of five to six or seven fathoms are those of the most vigorous growth of corals on the outer face of such barrier reefs or encircling reefs as I have examined in Fiji, a depth corresponding to that observed in the Bahamas in similar positions.

Some of the reefs on the northwestern face of Vanua Levu (Plate 4) apparently illustrate admirably the formation by denudation and erosion of small reef flats awash, and of reef flats destitute of islands or with islands encircling a shallow lagoon. It will be noticed that these flats and pseudo atolls rise from a comparatively shallow platform, — nine to twenty fathoms, — and evidently represent the different stages of denudation and of erosion of islands which have been left on one side of the reef flat, or have disappeared, leaving an irregular enclosing reef, or have

beach along Savu Savu, as well as Waikava and the adjacent islands, consists of coral upheaved to a height of thirty feet.

[1] Corals and Coral Islands, pp. 138, 278.

merely been denuded so as to be just awash; the scouring of the sea on the diminutive platform of submarine erosion having formed a shallow lagoon in the first instances mentioned, or a series of disconnected pools. These flats and atolls are in every way identical with similar reef flats or atolls formed from peaks or islands rising from great depths: Na Ndongu, Nuku i ra, Thakau Moi, Laukoto, and Thakau Levu Reefs (Plates **3**, **4**, **23ᵃ**, Figs. 8–19). See the similar structures of Thakau Nalolo, Thakau Utulei, and Nuku i ra, on the eastern part of the north shore of Vanua Levu (Plate **4**, Figs. 8–12).

From the eastern point of Savu Savu Bay and the western point of Vanua Levu the island is bordered by a fringing reef (Plates **3ᵃ**, **14**). Savu Savu Bay is protected by an extensive fringing reef off Savu Savu Point on the east, and by a series of wide barrier reef patches lying off Kumbalau Point on the west, and stretching in smaller disconnected patches across the southern face of the opening of the bay. To the west of Kumbalau Point runs an extensive plateau, the outer edge of which is from ten to twenty miles off shore, and varying in depth up to about thirty fathoms. On the outer edge of the plateau are narrow disconnected patches of corals and islets and rocks (Plates **3ᵃ**, **4**). The plateau makes out in two prominent points, one, Namena Reef, elliptical in shape, about twelve miles long and three miles wide, to the south of Kumbalau Point. The reef patches enclose an irregular lagoon, in the southern horn of which lies the island of Namena, about 320 feet in height (Plate **3ᵃ**). The other spit of the plateau is triangular in shape, and extends towards Makongai, from which it is separated by a channel 140 fathoms in depth. The western face of the plateau is bordered by a line of rocks and narrow coral patches, often widely separated, and extending in an undulating line.

The outline of the plateau as it forms the eastern side of Vatu i ra Channel is rounded, forming a deep bight off Solevu Point, and extending in a northeasterly direction towards Yendua Island. North of Passage Island (Plate **3**), 104 feet high, the coral patches lose their character of barrier reef flats; they become small, and are often very widely separated. The edge of the plateau is bordered with rocks, and the slope as we go north becomes less steep, passing off Solevu Point gradually into the deeper waters north of Vatu i ra Channel. But south of Nai Thombo thombo Point there are extensive reef flats, probably formed upon eroded flats of such detached spits as Lecupi Point on the south of Mbua Bay, and Lamut Islet north of Solevu Point. The principal one of these reef flats is Thakau Levu, on which some rocks are still awash at high water.

It is very probable that this plateau off the southwest coast of Vanua Levu represents the denuded and eroded slope of its western coast when it once extended near to the 100 fathom line. The only remnants of this former extension are the islands of Namena, Passage Island, and the numberless rocks and coral patches studded over the surface of the plateau and found along its edge.

The reefs of Makongai and Wakaya represent a stage of denudation and erosion less advanced than that of the Namena Reef, and of the reefs extending towards Vatu i ra Channel north of Makongai Channel.

From Cape Undu south the shores of Vanua Levu on both sides of Nateva Bay (Plate 4) are bordered by a fringing reef. From Savu Savu Bay the south shore is also protected by a fringing reef, which extends as far as Fawn Harbor; from there the fringing reef becomes a narrow barrier reef at a short distance from the shore, passing round Vienne Bay, and forming the Kioa Reefs, and the Florida and Texas reefs on the outer edge of the plateau upon which are the islands of Kioa and Rambe (Plates 4, 18). The horn of the Texas reef extends about five miles beyond Rambe, and returns to form a fringing and barrier reef on the north shore of that island, and connects with the barrier reefs off Kumbalau Point.

The Rambe Plateau (Plates 4, 18), as we may call the eroded eastern extension of Navukau Promontory, is another admirable example of the mode of formation by submarine erosion of such plateaus as those off the southwest coast of Vanua Levu, off the eastern point of Kandavu, and off the east face of Taviuni. The island of Rambe rises to a height of over 1,500 feet; it is nearly nine miles long, and about four and a half broad (Plate 18). Like Kioa, the other large island on the plateau, which is over 900 feet high, it is of volcanic structure. The plateau upon which these islands rise, and the accompanying islets, rocks, and patches, has a greatest depth of thirty-five fathoms, and an average depth of about twenty.

The Rambe plateau and the one to the east of Taviuni (Plates 4, 18), from which rise Ngamia and Lauthala, show more plainly than either Makongai or Wakaya the former connection with the larger islands of Vanua Levu and Taviuni. The promontory of which Cape Undu is the termination would, if denuded and eroded, have resulted in the formation of a plateau spit similar in all respects to that constituting the Namena barrier reef off the south coast of Vanua Levu. And finally the further disintegration of such irregularly shaped islands with encircling reefs as those of Makongai and Wakaya (Plate 15) would give us a ready explanation of the formation of such remarkably shaped reefs as the Nanuku and Nukusemanu Reefs (Plate 18), from the denudation and erosion of an extended ridge or line of the summits of independent islands, elevated at the time when the great masses of ancient limestones were raised to various heights perhaps up to one thousand feet.

The Great Sea Reef (Plate 1) appears on the chart as the continuation of the chain of which the Yasawa group of islands are the only remnants, and it may be that it represents its eastern continuation after its denudation and erosion, and transformation into a submarine platform for the growth of corals. Similarly the reefs extending to the east of Vanua Levu towards the Yasawa group may be the western extension of a range of which Sesaleka Peak and Yendua Islands formed prominent points.

GENERAL SKETCH OF THE FIJI ISLANDS AND CORAL REEFS.

I went to the Fijis under the impression that I was to visit a characteristic area of subsidence; for according to Dana and Darwin there is no coral reef region in which it is a simpler matter to follow the various steps of the subsidence which has taken place. Dana, in his last discussion [1] of the coral reef question, states that it is impossible to find a better series of islands than the Fijis to illustrate the gradual changes (brought about by subsidence) which take place in transforming a volcanic island with a fringing reef to one with a barrier reef, or to one with an encircling reef ring, and finally to one in which the interior island has disappeared and has left only a more or less circular reef ring. For these reasons one of the Fiji atolls promised to be an admirable location for boring and settling the question of the thickness of the coral reef of an atoll.

My surprise was great, therefore, to find within a mile from Suva an elevated reef about 50 feet thick, and 120 feet above the level of the sea, the base being underlaid by what is locally called "soapstone," [2] a kind of volcanic mud. The western extension of this reef can be traced at

[1] Am. Journ. of Science, Vol. XXX., August and September, 1885. Dana says: "The large Feejee group bears abundant evidence of subsidence in its very broad reef grounds, barrier islands, and atolls."

[2] The "soapstone" is largely composed of volcanic débris, mixed with tests of Foraminifera, Pteropods, and Mollusks. Brady (Q. J. Geol. Soc. London, 1888, Vol. XLIV. p. 1) considers the Rhizopod fauna such as one would expect from a depth of 150 to 200 fathoms.

points along the north side of the harbor of Suva (Plate 7), the islands of Lambeko, Vuo, and Dra-ni mbotu, which are respectively sixty to seventy feet in height, being parts of an elevated reef extending to low water mark, and now planed off. It was this elevated reef or its extension westward which we traced from the Singatoka River to the Nandi Waters (Plate 6). A short distance inland from the mouth of the Singatoka there is a bluff of about 250 feet in height, composed of coralliferous limestone. This bluff is the inner extension of the elevated patches and limestone bluffs visible on the shore of Viti Levu. I am informed by Dr. Corney that the islands of Viwa and Asawa i lau (Plate 3), to the northward of the Nandi Waters, are also remnants of this elevated limestone.

But the traces of extensive elevation are not limited to the island of Viti Levu. I found that the islands on the rim of the atoll of Ngele Levu (Plate 17) consisted entirely of coralliferous limestone rock, elevated to a height of over sixty feet on the larger island. The northern sides of the smaller islands Taulalia and Tai ni mbeka, as well as the north shore of Ngele Levu, were on the outer edge of the rim of the lagoon, deep water running up to the shore line. We next found that at Vanua Mbalavu (Plate 19) the northern line of islands were parts of an elevated reef, forming vertical bluffs of coralliferous limestone rock which had been raised by the central volcanic mass of the main island to a height of 510 feet at Ngillangillah, at Avea to 600 feet, at the Sovu Islands to 230 feet, and on the main island to a height of nearly 600 feet, while on the south of the main island the coralliferous limestone bluffs are very much lower, and those of Malatta and of Susui reach a height of 420 to 430 feet. Going farther west and south we find at Mango vertical bluffs of an elevated coralliferous limestone of over 600 feet underlaid by volcanic rocks at the sea level. At Tuvuthá the limestone bluffs are probably nearly 800 feet high. At Naiau they are more than 500 feet. At Lakemba (Plate 21) they reach a height of about 250 feet on the southwest side of the island, the greater part of the rest of the island being of volcanic origin. On the island of Aiwa (Plate 21) the elevated limestone is fully 200 feet thick. In the Oneata group the highest point of the elevated bluffs is about 160 feet (Plate 21). South of the volcanic island of Mothe and enclosed within the same barrier on the island of Karoni (Plate 22), the reef is about 120 feet thick.

On the three islands of the Yangasá group (Plate 22) the elevated limestone attains a thickness of 240, 300, and 390 feet, and on Ongea, the most southeasterly cluster we visited, it attains a thickness of nearly 300 feet. At Fulanga (Plate **22**) the elevated limestone attains a thickness of 360 feet, at Kambara (Plate **22**) it is about 200 feet thick, and at Wangava (Plate **22**) it is perhaps over 300 feet; these islands may be in part volcanic. Finally, at Vatu Leile, the most westerly island we examined, the elevated reef forming the island is fully 110 feet thick.

All this plainly shows that the western and southern part of Viti Levu, as far south as Vatu Leile, and the whole length of the windward islands of the Fiji group, from Ngele Levu on the north to Ongea on the south (Plate **2**), have been subject to an elevation of at least 800 feet; and there is abundant proof that the greater part of the thickness of the elevated coralliferous limestone has been eroded so as to reduce it in certain localities to the level of the sea, or in others to leave the bluffs and islands and islets of limestone which we have traced at so many points.

Unfortunately there are as yet but few soundings among the islands of Fiji (Plate **2**). There is a line extending from Nanuku Passage to the Kandavu Passage, and a number of soundings to the north of Wailangilala and towards Thikombia, which have developed the existence of an extensive plateau with a depth of between 300 and 400 fathoms, from which rise all the islands forming the northeastern extremity of Fiji (Plate **2**). The soundings between Ngau and Viti Levu (Plate **2**) also indicate shallower water to the west of that island than is found either east or south of it. The deep water extends northwesterly in the passage, parallel with Kandavu. Deep water (1,200–1,700 fathoms) is found in the triangle formed by Moala, Totoya, and Matuku (Plates **2, 16**), showing the steep slope of Moala, from 1,200 fathoms at a distance of six miles, and of Matuku of 1,400 fathoms at a distance of five miles.

The deep channel passing through the centre of the Koro Sea (Plate **2**) gradually deepens towards the south until it attains a maximum depth of over 1,400 fathoms east of Nairai and Ngau, becoming shallower towards Viti Levu (Plate **12**). The water gradually deepens also in the Kandavu Passage from over 1,100 fathoms north of North Astrolabe Reef to over 1,900 fathoms southwest of Kandavu. The soundings to the north of Naitamba indicate a ridge with somewhat over 500 fathoms in depth connecting the plateaus on the two sides of Nanuku Passage (Plates **2, 18**). There are no soundings showing the depths between the larger clusters composing the Lau or eastern group of Fiji. It would add greatly to our knowledge of the connection of these groups have lines of soundings connecting the different island clusters of Lau.

All the evidence to be gathered in Fiji tends to prove that preceding the present epoch there was an extensive elevation, which lifted the great masses of coralliferous limestone resting upon the flanks of the islands to a considerable height, in some cases as high as 1,000 feet. The base of the limestone masses rests upon volcanic rocks, as can be seen at Suva, at Kambara (Plate 78), at Mango, at Lakemba, at Naitamba, and at Vanua Mbalavu (Plate 72) it shows the thickness of the elevated reefs to have been over 800 feet. During this period of uplift the physiognomy of the islands of the group must have been greatly changed, and still further modified by the denudation and erosion which have taken place since the elevation of the ancient limestones. It is to the changes brought about by the elevation and the subsequent erosion and denudation that we must look for the causes which have fashioned the steep slopes of the islands and reefs, and not to the growth of the thin crust of corals which thrive upon the reef flats forming the substratum of the modern reef, — a substratum which in Fiji may be of volcanic origin or composed of elevated limestone, the sea face of which is the extension of the former land mass and follows its ancient slope, being only slightly modified by the growth of the crust of recent corals found upon it.

Similar elevated reefs (probably composed of the same tertiary limestone as those of Fiji) have been described by Clark[1] at the Loyalty Islands, and also by Chambeyron (L.),[2] and Pelatan (L.).[3] Chambeyron gives figures of the elevated terraces of Lifou and Ouvea composed of coralliferous limestone, and there is an excellent photograph taken by Pelatan of the elevated coral reefs of Lifou, and reproduced in Bernard's[4] Nouvelle Calédonie, p. 45. While Maré is said by Pelatan to have five terraces of elevated coralliferous limestone, and to be riddled with caverns,[5] Clark considers the elevated coralliferous limestones of the Loyalty Islands probably to be Pleistocene.

In the Solomon Islands, Guppy[6] has traced extensive elevated reefs,

[1] Q. J. Geol. Soc. London, 1847, Vol. III. p. 61.

[2] Bull. Soc. Géogr., 1875, p. 566, and Bull. Soc. Géogr., 1876, p. 634.

[3] Les Mines de la Nouvelle Calédonie.

[4] L'Archipel de la Nouvelle Calédonie, par Augustin Bernard. Paris, 1895.

[5] See also De Rochas, La Nouvelle Calédonie, p. 90. Grundman, Die Loyalty Inseln, Peterm. Mittheil., 1870, p. 365.

[6] Guppy, The Solomon Islands, 1887, p. 126, and Scott, Geog. Mag., 1888, p. 121, a criticism of the theory of subsidence as affecting coral reefs. Geol. of the New Hebrides, Friedrick, Q. J. Geol. Soc. London, 1893, XLIX. 227. Campbell, R., Geol. Soc. of Australasia, Melbourne, 1889, VI. 19. Strehl, Zeit. f. Wiss. Geog. Ergänz., No. 3, 1890. J. Walther, Bau d. Flexuren, Jena Zeits. f. Nat., 1886, p. 243. J. Garnier, Ann. d. Mines, 1867, p. 59. Walther, Adamsbrücke, Peterm. Ergänz., No. 102.

which however he considers as belonging to the present epoch. Elevated coralliferous limestones also exist in the New Hebrides as well as on the southern shore of New Guinea.

The time of this Fijian elevation we cannot at present ascertain. It is not unnatural to assume that it was coincident with the elevation of Northern Queensland, and that the area of elevation included New Guinea, the islands to the east of it as far south as New Caledonia, and as far east as the most distant of the Paumotus (Gambier Islands), and extended northward of that line to include the Gilbert, Ellice, Marshall, and Caroline Islands; and that since this epoch of elevation the islands within that area have been, like Northern Australia, subject to an extensive denudation and erosion, many of them being reduced to mere flats but a few feet above the surface of the sea, others worn away to represent to-day but a small portion of their former extent. It is upon the reef flats thus eroded, or around the islands and islets which are the remnants of a former period, that the corals of to-day have obtained a foothold. And further, by the mechanical actic ... he sea combined with that of the trade winds, channels have bee ... out of the substratum underlying the coral reefs to form t' ... the barrier reefs and atolls of Fiji.

So that, as far as we can judge from the case of ... nds, the shape of the atolls and of the barrier reefs is due ... hich have acted during a period preceding our own. T ... f the whole group have been elevated, and since their ... ave, like the northern part of Queensland, remained ne ... y, and exposed to a great and prolonged process of denu ... of aerial and submarine erosion, which has reduced them to ... esent height. The submarine platforms upon which the barrier reefs have grown being merely the flats left by the denudation and erosion of the central island, while the atolls are similar flats from the surface of which the islands have at first disappeared and the interior parts of which have next been removed by the incessant scouring of the action of the sea, the ceaseless rollers pouring a huge mass of water into the lagoon, which finds its way out of the passages leading into it or over the low outer edges of the lagoon. These atolls and islands, surrounded in part or wholly by encircling and barrier reefs, have not been built (as is claimed by Dana and Darwin) by the subsidence of the islands they enclose. They are not situated in an area of subsidence, but on the contrary in an area of elevation. The theory of Darwin and Dana is therefore not applicable to the Fiji Islands.

The evidence of elevation is not limited to that furnished by the remains of the elevated coralliferous limestone just mentioned, and it is natural to assume that the elevation we have just traced was but a [illegible] of a more general elevation, which perhaps took place in late tertiary [illegible] in which the whole group was involved. It is plain that there [illegible]een most extensive denudation and submarine erosion going on [illegible]t the group for a very considerable time, geologically speaking. The [illegible]lines of the islands, deeply furrowed by gorges and valleys, the sharp or serrated ridges separating the valleys, the fantastic outlines of the peaks and chains of Viti Levu, Vanua Levu, and Ovalau, all attest to the great work of atmospheric agency which must have been going on for so long a period.

The extent of the separation of the islands, islets, or isolated rocks from the points or spurs of the larger islands also bears witness to the great length of time during which submarine erosion and denudation have been at work.

The platforms of submarine erosion constitute the characteristic features of the islands of Fiji. A glance at the sketch map of Fiji (Plate 1) and at the detailed charts of different portions of the group cannot fail to show how extensive this action has been. I need only call special attention to the northwestern extremity of Viti Levu, the eastern face of the same island (Plates **3**, **7**), the southern coast of Viti Levu (Plate **5**), the southwestern and northeastern shores of Vanua Levu (Plates **3**, **4**, **18**), the extensive platform of Kandavu (Plate **11**), that of the northern extremity of Taviuni, Budd Reef (Plates **4**, **18**), Thikombia (Plate **11**), the platforms of submarine erosion of Mbengha (Plate **8**), of Nairai, Ngau (Plates **12**, **13**, **14**), of Makongai and Wakaya (Plate **15**), of Moala and Totoya (Plates **16**, **23**), of the Exploring Isles (Plate **19**), and of the smaller islands like Kimbombo and Kanathea (Plate **19**), Lakemba and Oneata (Plate **21**), Mothe, Komo, Yangasá, and Ongea (Plate **22**), and a host of other smaller platforms. Finally, platforms of submarine erosion which have reached the stage of atolls of greater size, like the Argo Reefs (Plate **21**), Reid (Plate **20**) and Nanuku Reefs (Plate **18**), Ngele Levu (Plate **17**), or those of smaller dimensions, like Adolphus Reef (Plate **18**), Thakau Mata Thuthu, Thakau Vutho Vutho (Plate **17**), Duff (Plate **18**), Dibble's Reef (Plate **19**), Motua Levu, Motua lai lai (Plate **18**), Thakau Tambu (Plate **20**), Thakau Lekaleka (Plate **21**), Thakau Motu (Plate **22**), Thakau Levu (Plate **22**), and others.

Add to this the fact that we are in a region of a former powerful and extensive volcanic activity, the traces of which can still be seen in all directions, and which has undoubtedly played a great part in the lifting of the island masses and their subsequent shaping to their present outlines. From this evidence I am inclined to think that the corals of to-day have actually played no part in the shaping of the circular or irregular atolls scattered among the Fiji Islands, that they have had nothing to do in our time with the building up of the substructure of the barrier reefs encircling either wholly or in part some of the islands, that their modifying influence has been entirely limited in the present epoch to the formation of fringing reefs, and that the recent corals living upon the outer margin of the reefs, either of the atolls or of the barriers, form only a crust of very moderate thickness upon the underlying base. This base may be either the edge of a submarine flat, or of an eroded elevated limestone, or of a similar substructure composed of volcanic rocks, the nature of that base depending absolutely upon its character when elevated in a former period to a greater height than it now has; denudation and erosion acting of course more rapidly upon the elevated coralliferous limestones than upon those of a volcanic character. It is therefore natural to find that the larger islands, like Kandavu, Ovalau, and Taviuni (Plates **1, 3, 4, 7, 10, 11**), are of volcanic origin, while the islands which once occupied the area of the lagoons of Ngele Levu, Nanuku Reefs, Vanua Mbalavu, the Argo Reefs, the Oneata, Yangasá, Aiwa, Ongea, and Vatu Leile clusters, were composed of elevated coralliferous limestones. They have disappeared almost entirely, leaving only here and there a small island to attest to the former existence of a more extensive elevated limestone, once covering the whole area of what is now an atoll (Plates **1, 17, 18, 19–21**). Smaller volcanic islands, like Matuku, Moala, Ngau, Nairai, and Koro (Plates **1, 12, 13, 14, 16**), also show the greater or smaller extent to which each has been eroded after its elevation, being least in Koro (Plate **3**[a]) and Matuku (Plate **16**), and somewhat more in Moala (Plate **16**) and Ngau (Plate **13**), and still more in Nairai (Plate **14**), while in such volcanic islands with atolls as Mbengha (Plate **8**), Wakaya, and Makongai (Plate **15**) the denudation and submarine erosion[1] has been still greater, the islands covering but a comparatively

[1] Dana (p. 230) accounts for the formation of the shore platform by the action of the sea. We go a little further, and assign to the action of the breakers and of the currents in carrying loose material to sea the formation of channels between the outer reefs and the shore; these become lagoons inside of barriers or encircling reefs, and finally scoop out the lagoons of atolls. Dana (p. 181) insists fully as strongly as Darwin upon the identity of origin of the encircling atoll reef and the outer reefs enclosing high or low islands: "The lagoons are similar in character and position

small area of that once covered by the island originally occupying the area of the lagoon; this denudation having been carried to a still greater extent in the Kimbombo cluster (Plate **19**), in Komo (Plate **22**), and the islands of Duff Reef (Plate **18**). This process of denudation and submarine erosion may have gone so far as to leave no trace in an atoll of its volcanic or of its limestone (elevated) origin, its shape to-day being entirely due to mechanical action, and having nothing to do with the growth of the corals which have found a footing upon the flats due to submarine erosion and to denudation and to the action of the atmosphere and of the sea.

It seems to me as if the position of an island left on the western or lee edge of a lagoon depended upon the original position of its highest point. This appears in the case of Makongai and Wakaya. The crest of the former was probably near the eastern edge, while the highest point of Wakaya was perhaps nearest the western side of the original island (Plate **15**). Similarly the highest summit and ridge of Vatu Léile, if our views are correct (Plate **9**), was on the western face of the original land mass. The highest ridge of Rambe lies on the northwestern side of the submarine plateau; the islands of Budd Reef indicate its highest land to have been on the northern part of the plateau (Plate **18**). In Mbengha (Plate **8**), on the contrary, the highest land mass is found on the east face of the lagoon. In the Great Astrolabe Lagoon it was in the central line of the plateau (Plate **10**). In Ngau (Plate **13**) the highest land lies to the east, in Nairai (Plate **14**) somewhat nearer the centre, in Moala in the northern part of the lagoon. In Totoya (Plate **23**) the highest part of the rim is the eastern edge.

The northeastern part of Ngele Levu must have been the highest extremity of the Ngele Levu land mass (Plate **17**). The islet at the northeastern extremity of Wailangilala (Plate **18**) indicates the position of the highest part of that atoll. The highest land of Naitamba, Kanathea, Vanua Mbalavu, and Katavanga lies on the western part of the plateau (Plate **19**), and also that of Lakemba (Plate **21**).

The highest of the land masses of Aiwa, of Oneata (Plate **21**), and of Komo (Plate **22**) was on the southern edge of these plateaus. In Mothe it lay near the northern extremity (Plate **22**). In Namuka and Ongea it ran through the central parts of the group (Plate **22**). In Fulanga the land seems to have been equally high on the northern and

to the inner channels within barrier reefs. . . . The reefs within the lagoons correspond very exactly in mode of growth and other characters to the inner reefs under the lee of a barrier."

southern edges of the land mass (Plate **22**). In Yangasá the south-eastern and western faces were probably the hi[illegible] (Plate **22**).

Admiral Wharton[1] has suggested " [illegible] islands by the action of the sea, and tha [illegible] share in furnishing coral foundations than has been generally admitted." From our experience in Fiji we may safely modify this to the cutting down, not only of volcanic islands, but also of other elevated islands, and their cutting down not only by submarine erosion but also by denudation and atmospheric agencies, and thus preparing the foundations upon which recent corals have established themselves. Add to this the elevation of banks composed of volcanic rocks or of sedimentary rocks up to heights at which corals or corallines can begin to grow, and we have in addition to their increment in height from the increase due to pelagic organisms and the decay of other calcareous invertebrates living upon their surface all the elements needed for the preparation of a set of foundations from very different causes.

I have already on other occasions called attention to the powerful scouring effect produced upon the interior of an atoll or lagoon, or the channel of a barrier reef, by the mass of water poured into it from all sides as the huge ocean swells break over the outer rim. This mass of water can find no outlet against the incessant swell; it must escape to leeward through the openings in the outer reef flats, or laterally over the low parts of their outer edges. It will be noticed that the openings are usually on the west face of the atoll, the direction in which the prevailing trades drive the water of the lagoon. The water becomes charged with particles of lime or of other material, and we soon have all the elements of a modified gigantic pothole, from which the churned material[2] is carried out by the currents flowing through the entrances into the lagoon. It has long been known that there is a violent rush of water out of the lagoons, the velocity attained reaching sometimes four to five knots. In Fiji I have noticed these powerful currents flowing out of the passages leading into the lagoons of Fulanga (Plate **22**), of Ngele Levu (Plate **17**), of Wailangilala (Plate **18**), of Vatu Leile (Plate **9**), of Totoya (Plate **23**), and racing along the interior channels of the great

[1] "The Foundation of Atolls," Nature, February 25, 1897, p. 391.

[2] Material derived mainly from the mechanical disintegration of the corals or substratum forming the surface of the reef, and also in part from the chemical disintegration due to the sea water at work to rot and dissolve the limestones of the reef.

barrier reef stretching along the south coast of Viti Levu, especially at Lauthala Bay, Suva (Plate **7**), and the reef harbors and passages between Suva and Serua (Plate **5**), and out of the smaller atolls like Motua lai lai, Thakau Leka leka, Thakau Momo, and others (Plates **12**, **18**, **21**).

The strength of the currents in the channel separating the barrier reef and the shore has been noticed by Semper[1] and by Möbius[2] as bearing an important part in Mauritius. There is in the Biologisches Centralblatt, 1889–90, Bd. IX. p. 564, a short review of the third edition of Darwin's "Coral Reefs," showing the principal points in the discussion of the reefs to which Bonney has called attention. But this discussion is mainly theoretical, and adds no new factors in the problem. I would refer to what Gardiner[3] says regarding the conditions affecting the growth of coral reefs in Fiji, where he shows the effect of tidal currents in the passages of reefs and inside of reefs. Strong currents prevent the coral larvæ from fixing themselves in localities which they scour, while the corals will thrive off the passages where the currents have lost their strength. The navigators and naturalists of the U. S. Exploring Expedition[4] frequently speak of the rapid outward current passing through the openings of the reefs, especially during the ebbing tide. Dana[5] had noticed the great strength of the tidal currents, and he well explains by their action the great diversity of distribution of material over the bottom of a lagoon or of a barrier reef channel.

There seems to be no question that the action of the sea can cut out the lagoons of barrier reefs and of atolls at the depths at which they have been observed in the Fijis. Although there are individual atolls which show depths of thirty-five to fifty fathoms and even more, these are exceptional depths, which are readily explained as due to other causes than the scouring action of the sea.

Admiral Wharton[6] has given an excellent summary of cases showing to what depths the action of the sea in motion may be felt to a sufficient extent to move material at depths of fifty to sixty fathoms. As he justly says, "The effect [of the action of the waves in an otherwise deep sea over which strong winds are continually blowing] will be to cut down an island more or less rapidly, according to its constitution, to a very considerable depth below the surface, the final result being a perfectly flat bank."

1 Natürl. Existenzbeding. d. Thiere, Bd. II. (1880), chapters 7, 8.
2 Beiträge z. Meeres Fauna der Insel Mauritius, Berlin, 1880, p. 29.
3 *Loc. cit.*, p. 484.
4 Dana, p. 170.
5 *Loc. cit.*, p. 151.
6 Nature, Vol. LV. p. 392.

On Plate 22[b] I have a series of hypothetical figures to illustrate the changes I imagine the islands of Fiji to have undergone from the time of their elevation to the present day. The only type which is not represented is that of Koro, which is however sufficiently well shown on Plate 19[a], Fig. 8. The highest point of Koro occupies a nearly central position, the eastern platform of submarine denudation being only slightly wider than the western. Koro occupies a position intermediate between Makongai and Wakaya (Plate 22[b], Figs. 2, 3), where in the one case the widest platform of submarine erosion is situated on the west side, and in the other on the eastern face of the island.

The dotted lines surmounting the Figures of Plate 22[b] indicate the hypothetical islands as they may have appeared after their elevation to the highest point; the solid lines indicate the heights of the islands as they are at the present day, and the lower dotted lines in Figures 7 to 12 indicate the position of the underlying volcanic rocks which have elevated the overlying coralliferous limestones in Figures 7 to 11, while in Figure 12 the volcanic rocks of Vanua Mbalavu are seen to pass under the elevated limestones of Thikombia i lau.

In Plate 20[a], Figures 1 to 5, the dotted lines represent the position of the volcanic rocks underlying the recent coral reefs forming the barrier of the harbor of Levuka, upon the platform of submarine erosion consisting of volcanic rocks, as represented by the dotted lines in those Figures.

Figures 1 to 5 represent the hypothetical outlines of volcanic islands. Figure 1, that of Nairai, with a narrow barrier reef off the east coast and a wide platform of submarine erosion on the western face, with heads and patches which probably represent higher points of the original Nairai as indicated by the dotted lines. Figures 2 and 3 represent modifications of a volcanic island having probably in one case its highest point nearest the eastern edge of the lagoon, and in the other nearest the western side of the lagoon (Makongai and Wakaya).

Figure 4 represents Mbengha, in which there must have been a western ridge, and perhaps also a central ridge, more or less parallel with the two main ridges of Mbengha near the eastern edge of the lagoon.

Figure 5 represents the continuation of a former great ridge northward from Kandavu towards the North Astrolabe Reef, which has been denuded and eroded into a series of islands now existing in the Great Astrolabe Lagoon.

Figures 6 to 11 represent the former outlines of islands composed of elevated coralliferous limestone. In the case of Figure 6, Tuvana i ra, the central limestone hill is flanked by two nearly equal platforms of submarine erosion which are scarcely more than reef flats. In Figures 8 and 10 are represented conditions in which, as in Vatu Leile, we have a very shallow lagoon with reef flats both on the east and west, and the remnant of the original island rising to a hundred feet at the western face. In Figure 10 we have the eastern end of the Ngele Levu Lagoon, with the islet of Taulalia on the north side of a shallow lagoon. Immediately beyond Taulalia all trace of the former elevated island composed of limestone disappears; the lagoon becomes deeper as we pass to the western entrances, and the only traces left of the original Ngele Levu Island are the extensive reef flats on the north and south side of the deeper lagoon.

Figures 9 and 11, Ongea and Oneata, indicate the amount of erosion and denudation which probably has taken place to reduce the islands as originally elevated to their present condition.

Figure 7 represents the manner in which the great central Sound of Fulanga, with its narrow outer lagoons, has probably been formed by the denudation and erosion of the central part of the limestones composing the island, aided by the solvent action both of the fresh water finding its way through the central limestone mass, and that of the salt sea after it had once gained access to the inner Sound of Fulanga.

Figure 12 gives a hypothetical section across Vanua Mbalavu, showing the extension westward of the volcanic rocks which have raised the island of Thikombia i lau, near the central part of the lagoon, composed of elevated limestone. The elevated limestone to the westward of Thikombia either having all been denuded and eroded or broken up into masses readily decomposed, the fragments of which still exist to the northeast towards Ngillangillah and south towards Malatta Island.

The sections which I have given (Plates **11**[a], **17**[a], **19**[a], **20**[a], **22**[a], **22**[b]) plainly indicate the general flatness of the lagoons, with a slight inclination in the direction of the flow of the water in the lagoon toward the ship passages leading into the lagoon, and the outline of the islands which have first been cut down by atmospheric agencies show irregularities which disappear finally when they have come within the scope of submarine erosion, resulting in such "sunken" banks as the Penguin Bank (Plate **23**[a], Figs. 7, 13). By "sunken" we do not mean in any way to refer to subsidence as a factor in producing such a bank. The mass of water which is poured into a lagoon on the windward face of a reef, and transforms it into a gigantic pothole, is something enormous. The breakers follow one another incessantly, and the hydraulic head obtained is amply sufficient to account for the scouring of the lagoons after the reef has once established itself as a bank, and amply sufficient to wear away from the slope of the islands the platform upon which the coral reef is built. The topography of this platform is naturally much varied, depending upon the character of the shore line, the direction of the valleys of the shore hills, and their composition. A glance at the charts accompanying this Bulletin will show all possible conditions of submarine erosion in the cutting down of the submarine platforms of the islands of Fiji, and in the manner in which islands, islets, and rocks have been left, attesting their former greater extension in the various clusters of the Archipelago.

When the principal openings are not on the lee side of the lagoons, as is the case with Vanua Mbalavu (Plate **19**), and the Argo Reef or Totoya (Plate **23**), Fulanga (Plate **22**), and a few others, there is usually a simple reason, such as the lower elevation of the island once covering the area of the lagoon at some point not on the lee side, or the fact that the lagoon has been formed on a steep volcanic slope looking eastward or northward, so that deep ravines or tongues of deep water cut into the lagoons, and intercept the coral patches forming its rim on the weather side, and thus leave a windward passage. It is by some such orogenic condition that we must explain the existence of deep soundings within atolls, — soundings which in no way indicate a subsidence, as has been assumed by Darwin, and which according to him were not to be explained by any other hypothesis. Such deep ravines are of course also to be traced on the slopes of the larger islands where we find, crossing the shallow plateaus on which coral patches grow, valleys of considerable depth, which appear as deep soundings within the area of an outer reef flat such as in the great plateau off Viti Levu and Vanua Levu (Plates **3**[a], **4**), or of Kandavu (Plates **10**, **11**) and Taviuni (Plate **4**), which according to Darwin would indicate a subsidence, while, on the contrary, they are a part of the results of the elevation and lifting up of that region of Fiji.

Nor are the great depths found close to narrow lines of corals an indication that the corals have grown up as a nearly vertical wall from a depth of two to three hundred fathoms or more. It merely indicates that the corals form a thin crust, at most 120 feet in thickness, over a sharp volcanic ridge, the summits or crest of which have either reached by elevation the depths at which corals can grow, or have been denuded by submarine erosion to form a platform below the level of the sea, where corals have found a footing upon them.

My observations in Fiji only emphasize what has been said so often, that there is no general theory of the formation of coral reefs, either of barrier reefs or atolls, applicable to all districts, and that each district must be examined by itself. At least such has been my experience in the Bermudas, the Bahamas, Cuba, Florida, the West Indies, the Sandwich Islands, and Australia. The results of this trip show plainly that Darwin's theory is not applicable to the Fiji Islands, notwithstanding the borings at Funafuti, and that, in all the cases I have examined, the reefs form but a thin crust upon the underlying base, the shape and composition of which is not in any way due to the growth of corals of the existing period.

CAMBRIDGE, MASSACHUSETTS,
October 1st, 1898.

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Northwest Side of Ono Island, volcanic, inside of Great Astrolabe Reef Lagoon.

PLATE 52.

Yaukuve lai lai Island, volcanic, seen from the west, inside of Great Astrolabe Reef Lagoon. Ono in the distance.

PLATE 53.

Solo Rock Lighthouse, North Astrolabe Reef Lagoon.

PLATE 54.

Solo Rock, volcanic, North Astrolabe Reef Lagoon.

PLATE 55.

West Face of Wakaya Island, volcanic. Surf on Fringing Reef.

PLATE 56.

North Shore of Wakaya Island, volcanic, forming south side of Boat Passage leading into Wakaya Lagoon.

PLATE 57.

Looking into deep Bay on east side of Moala, volcanic, from outside of Barrier Reef.

PLATE 58.

Southwestern side of Nairai, volcanic, seen from Anchorage inside the Lagoon.

PLATE 59.

Kobu Island, volcanic (Magnetic Island), inside of Nairai Lagoon, seen from the north.

PLATE 60.

Islets (Mbuimbani to left) off north point of Taviuni Island, volcanic.

PLATE 61.

Kimbombo Islands seen from the east, distant two and a quarter miles; to the left, Volcanic Island, and Elevated Limestone to the right.

PLATE 62.

Eroded Shore Line, Volcanic Rocks, Islands of Lau. From a Photograph by E. G. Jones, Esq. (Thithia teste Andrews.)

PLATE 63.

Northeast Point of Komo, Volcanic Rock Outlier.

PLATE 64.

Beach on the North Shore of Komo, Volcanic Rocks, Komo Ndriti in the distance.

PLATE 65.

Pocillopora Fringing Reef Flat, Komo Island.

PLATE 66.

East Rim of Totoya, seen across the Isthmus, inside the Lagoon of the Western Coast of the Island of Totoya.

PLATE 67.

Opening into the Totoya Crater Basin, seen from the West approaching the "Gullet," inside the Lagoon.

PLATE 68.

Islets to the West of the "Gullet," looking into the Totoya Crater Basin from the Entrance into the "Gullet."

PLATE 69.

Islet off the Inner Edge of Northern Rim of Totoya, seen facing the Eastern Inner Rim of the Crater.

PLATE 70.

Eroded Rim of Crater Basin of Thombia, Budd Reef Lagoon, Ringgold Isles.

PLATE 71.

Crater of Haleakala, Hawaian Islands, from a height of about 2,000 feet on the edge of the rim.

PLATE 72.

Northeast side of Vanua Mbalavu Island, seen from inside of the Lagoon. The low ridge along the shore consists of elevated limestone, also the conical hill to the left; the rounded hills in the background are part of the volcanic nucleus of the island.

PLATE 73.

Northeast Point of Ngillangillah Island, inside Vanua Mbalavu Lagoon, seen from the East. Elevated limestone.

PLATE 74.

Cañon, east shore of Ngillangillah Island, Vanua Mbalavu Lagoon. Elevated limestone.

PLATE 75.

Avea Island (600 feet). Vanua Mbalavu Lagoon. Elevated limestone.

PLATE 76.

Alcyonarian Flat, Ngillangillah Island.

PLATE 77.

Limestone Bluff north of Tokolau Beach, Kambara, Wangava in the distance.

PLATE 78.

Volcanic Hill south of Tokolau, Kambara. The elevated limestone extends to the valley on left of hill. The negro-heads and shore platform underlying the limestone are volcanic.

PLATE 79.

Elevated Limestone Cliffs, Northwest Shore of Kambara. Neither fringing nor barrier reefs along this part of the coast.

PLATE 80.

Southeast Side of Fulanga. High hills in the southeast corner; shore line of low limestone hills in the foreground, seen from outside of barrier reef.

PLATE 81.

Looking into Fulanga Lagoon and Sound. Limestone islets across the rim of the Sound. Limestone islets and hills in the distance.

PLATE 82.

Entrance into Fulanga Lagoon and Sound, seen from the east.

PLATE 83.

Limestone Islets in Fulanga Sound, and Islets across eastern Margin of Sound. From a Photograph by Mr. Hathaway. Limestone Bluffs of Inner Rim of Sound looking east.

PLATE 84.

Undercut Limestone Islets in Fulanga Sound. From a Photograph by the Hon. W. L. Allardyce.

PLATE 85.

Low Gap, looking across Barrier Reef, into closed Sound of Northeast Coast, Mango.

PLATE 86.

Elevated Limestone Bluffs, East Coast of Mango. To the right along the beach the volcanic rocks underlying the limestone crop out.

PLATE 87.

Volcanic Islets on the southwest side of Mango, on the edge of the Barrier Reef.

PLATE 88.

Northwest Point of Tuvuthá. Elevated limestone (800 ft.).

PLATE 89.

Southeast Point of Tuvuthá. Elevated limestone.

PLATE 90.

Yavutha Island (240 ft.). Elevated limestone, distant 1½ miles from the southeast inside of Yangasá Lagoon.

PLATE 91.

Looking into Bay on north side of Navutuiloma Island, Yangasá Lagoon. Elevated limestone.

PLATE 92.

Point (elevated limestone) on North Shore of Navutuiloma, Yangasá Lagoon. Yavutha Island in the distance.

PLATE 93.

Islets (elevated limestone) in Bay of Navutuiloma, Yangasá Lagoon.

PLATE 94.

North Shore of Ongea Ndriti (elevated limestone).

PLATE 95.

Taulalia Islet, distant two miles, northern edge of Ngele Levu Lagoon. Seen from Anchorage inside of Lagoon. The cones are composed of elevated limestone.

PLATE 96.

Northern Point of Tai ni Mbeka Island, elevated limestone, northern edge of Ngele Levu Lagoon.

PLATE 97.

Pitted and Honeycombed Surface of central part of Ngele Levu Island, with typical inland vegetation.

PLATE 98.

Pitted and Honeycombed and Denuded Surface of Ngele Levu Island near eastern shore, with conical mounds and deep crevasses.

PLATE 99.

Vegetation, West Shore of Ngele Levu Island.

PLATE 100.

Elevated Limestone Bluffs, Northwest Shore of Vatu Leile, seen across barrier reef line.

PLATE 101.

Vatu Savu Islets (elevated limestone) on northern edge of Vatu Leile Lagoon. The low eastern shore of the island of Vatu Leile (elevated limestone) in the background.

PLATE 102.

Vatu lai lai Islets (elevated limestone) northern rim of the Vatu Leile Lagoon.

PLATE 103.

Southern Horn of Nanuku Levu, seen from the south. Nanuku Levu Island in the distance.

PLATE 104.

Nanuku Levu Island, seen from the west across the Western Reef.

PLATE 105.

Southern Reef Flat of Nanuku Levu Island.

PLATE 106.

Beach Rock on East Shore of Nanuku Levu Island.

PLATE 107.

Negro-Heads (elevated limestone) occupying Position of Nanuka lai lai Island.

PLATE 108.

The Islands of Nuku Mbalate and Nuku Mbasanga, seen from the west across the encircling reef.

PLATE 109.

Western Point of Wailangilala Island, distant one third of a mile from anchorage inside the Lagoon.

PLATE 110.

Northeast Point of Wailangilala Island, seen from Lighthouse Tower.

PLATE 111.

Southeast Horn of Thakau Lekaleka, Oneata Passage.

PLATE 112.

Northeast Horn of Motua lai lai, seen from the east.

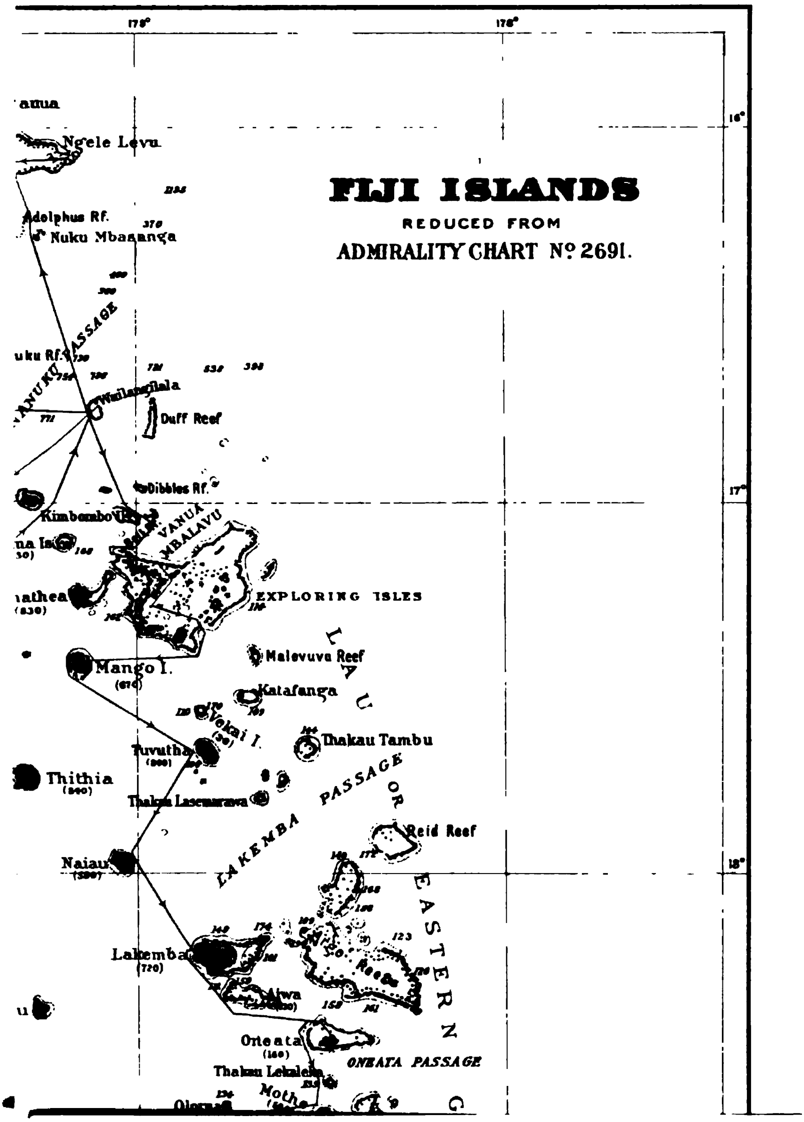
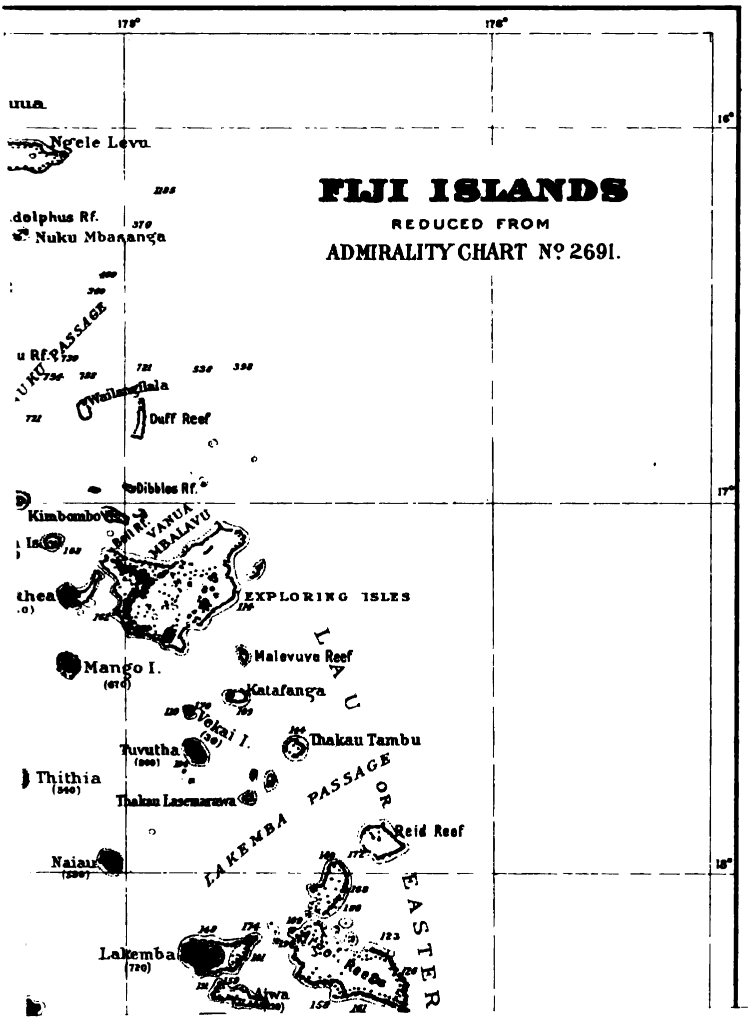
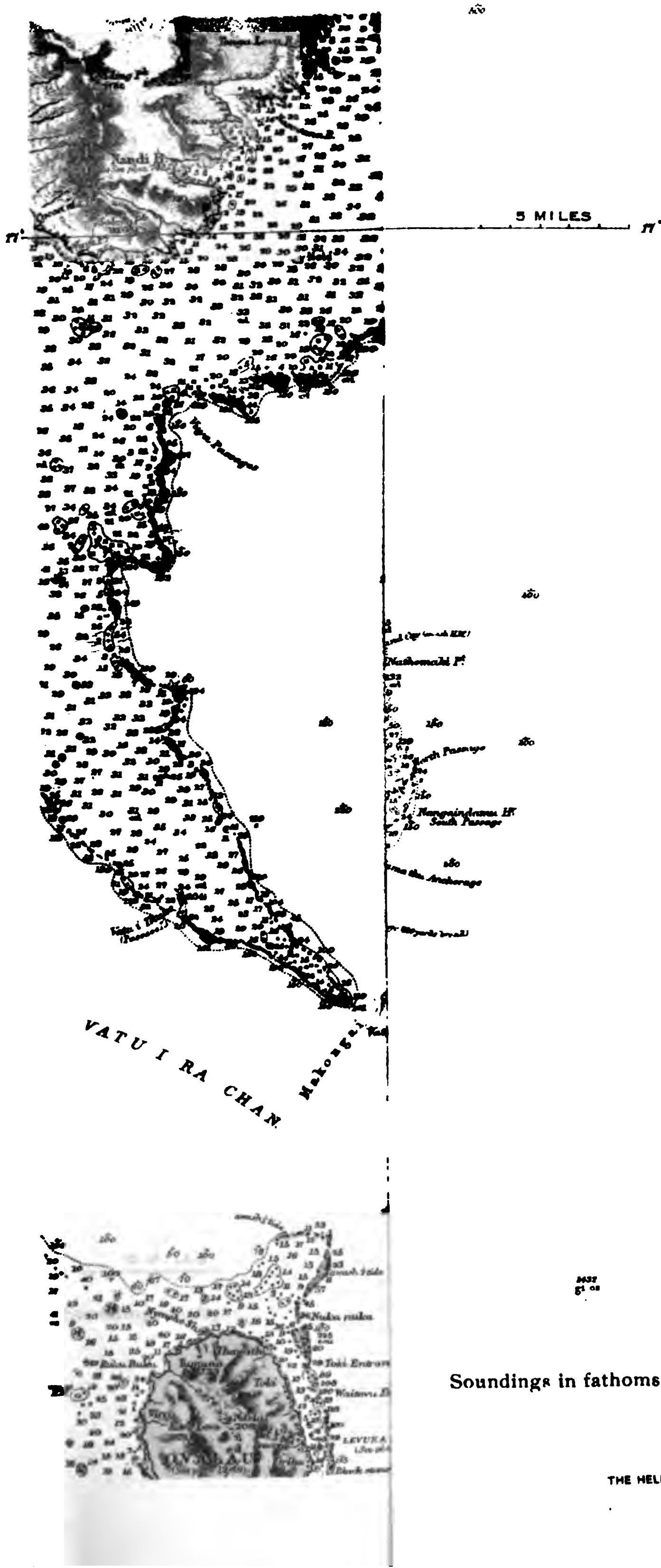

FIJI ISLANDS
REDUCED FROM
ADMIRALITY CHART No. 2691.
Ngele Levu
Adolphus Rf.
Nuku Mbasanga
Duff Reef
Dibbles Rf.
Kimbombo
VANUA MBALAVU
EXPLORING ISLES
Malevuva Reef
Mango I.
Katafanga
Thakau Tambu
Thithia
Tuvutha
Naiau
LAKEMBA PASSAGE
LAU OR EASTERN G
Reid Reef
Lakemba
Oneata
ONEATA PASSAGE
Thakau Lekaleka
Mothe

PLATE 2.


FIJI ISLANDS
REDUCED FROM
ADMIRALITY CHART Nº 2691.
Ngele Levu
Nuku Mbasanga
Duff Reef
Dibbles Rf.
Kimbombo
VANUA MBALAVU
EXPLORING ISLES
Mango I.
Malevuva Reef
Katafanga
Vekai I.
Tuvutha
Thakau Tambu
Thithia
Thakau Lasemarawa
LAKEMBA PASSAGE
Reid Reef
Naiau
Lakemba
Aiwa
EASTER
16°
17°
18°

PL. 3.


Sugar Loaf
Mbua B.
Nandi B.
Vaya Passage
Vatu-i-ra Chan.
Broad Passage
Thakau Ndavui
Nuku-nuku
Levuka
Na-lulu
Moturiki
Moturiki Channel
Rocks (4ft high)
Wai Rua
Wai Maro
Mata Vada
Tai Vungalei
District
Dravuni
Naitasiri
Namara
Mbau Roads



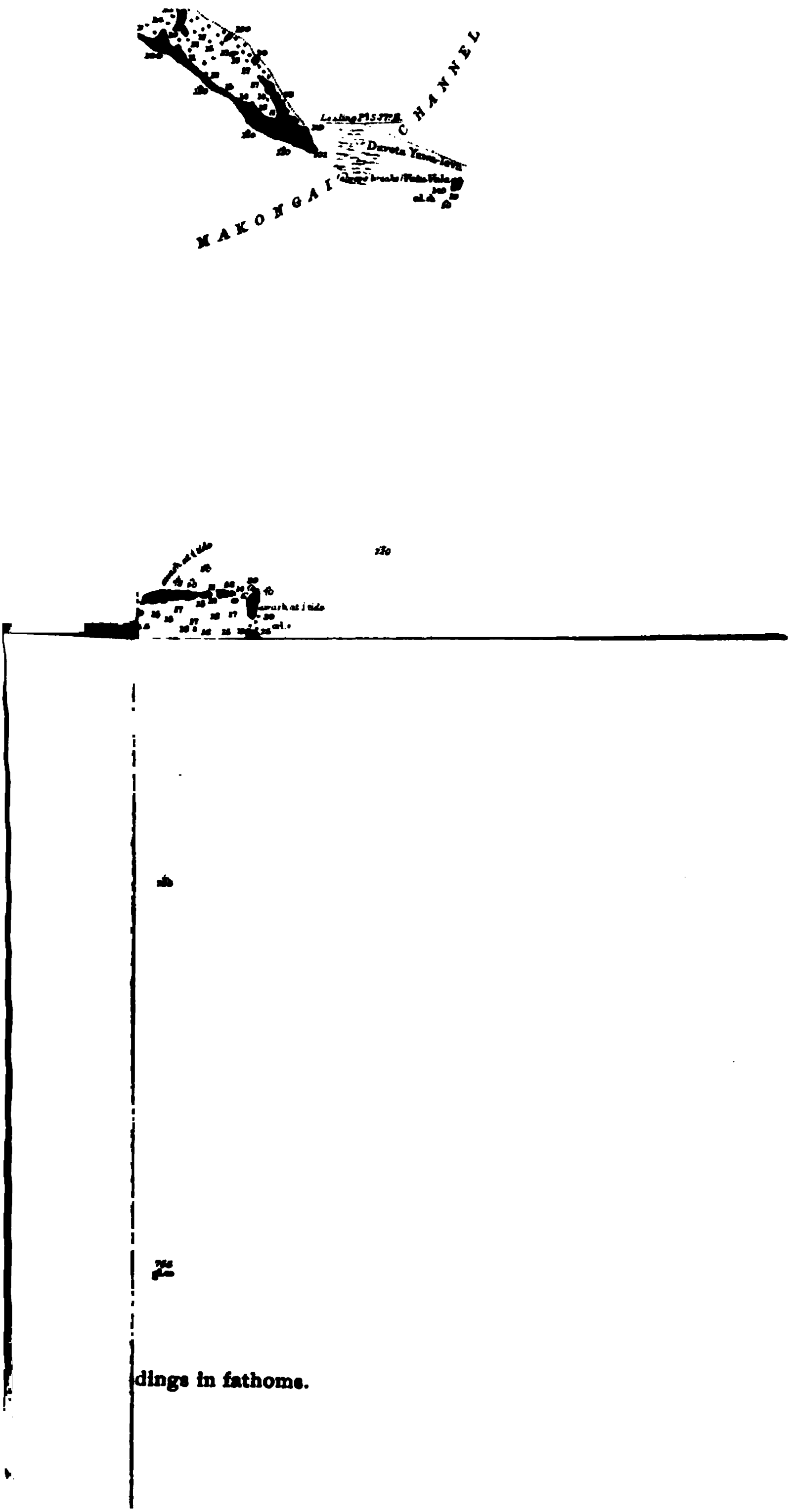
Soundings in fathoms.

THE HELIOTYPE PRINTING CO., BOSTON

Soundings in fat

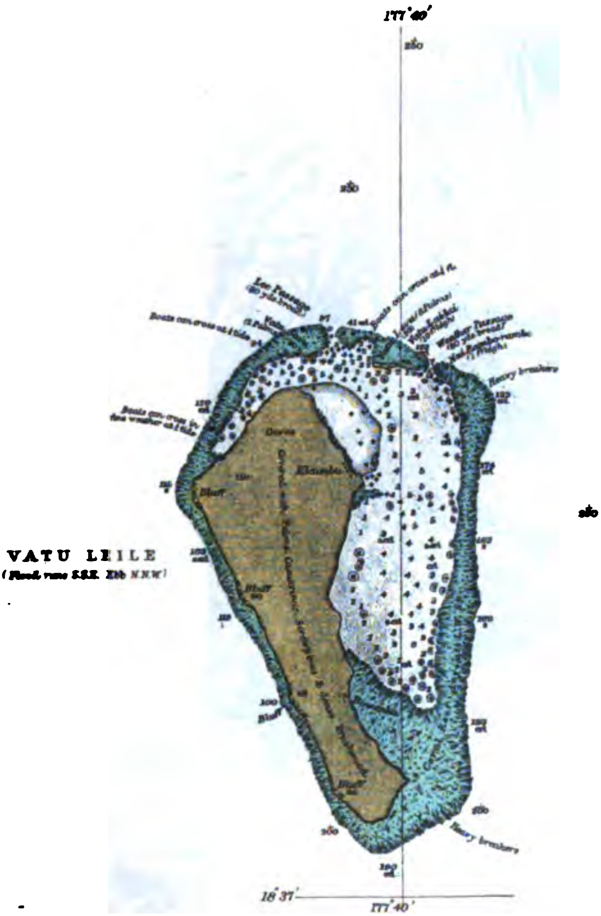
U

PL. 7.



18° 30′

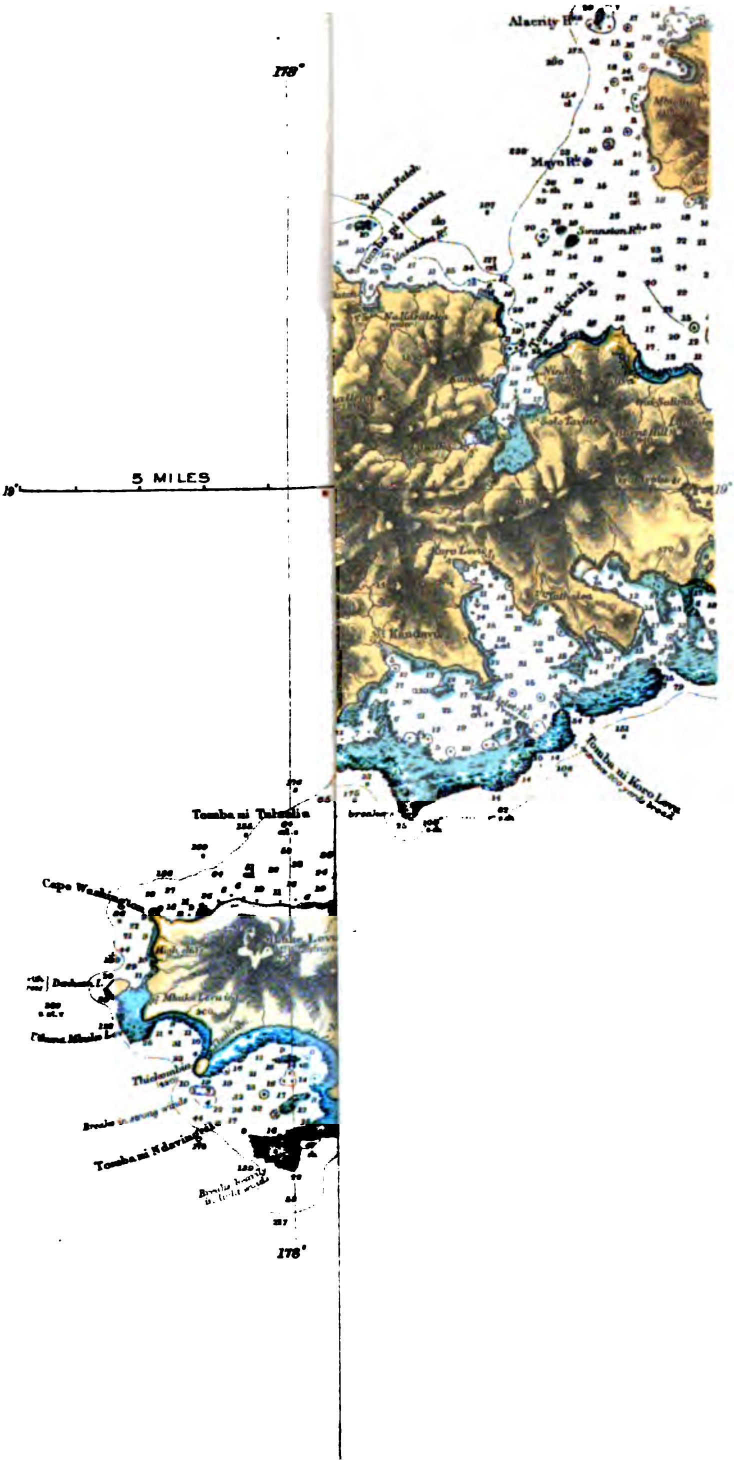
THE HELIOTYPE PRINTING CO., BOSTON



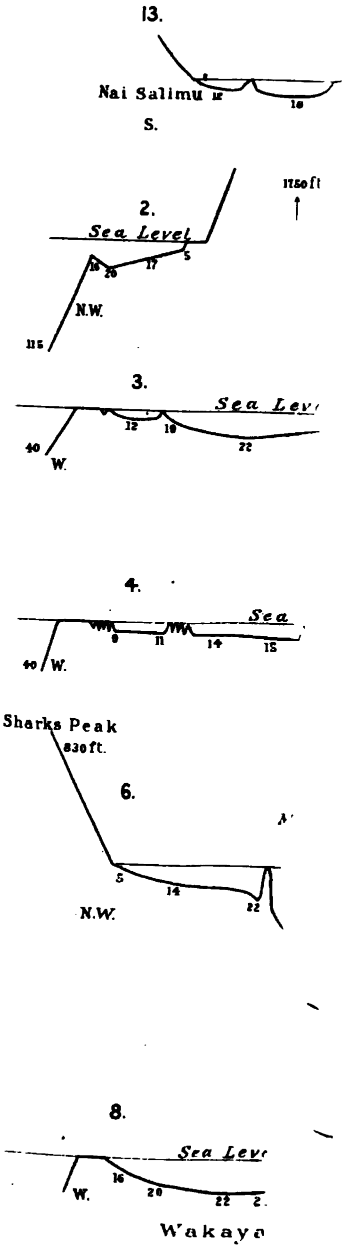
Soundings in fathoms.

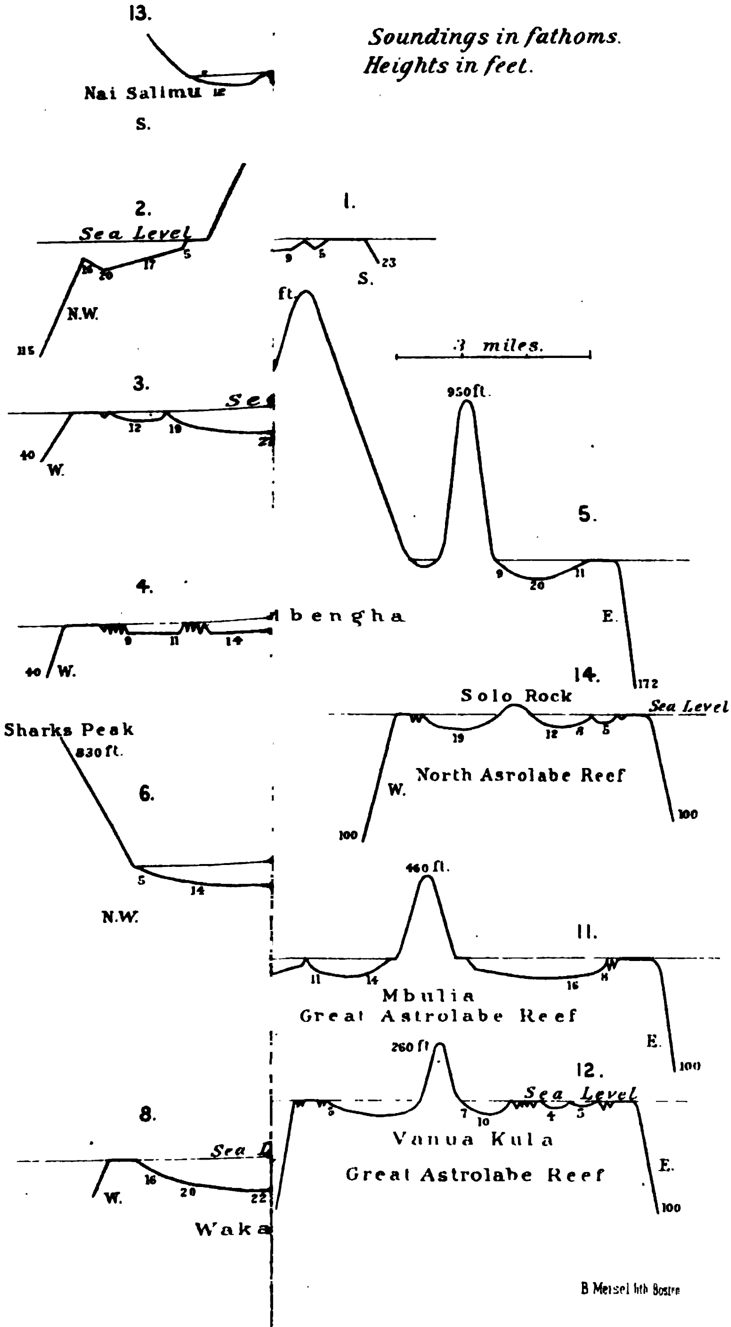
5 MILES

THE HELIOTYPE PRINTING CO., BOSTON

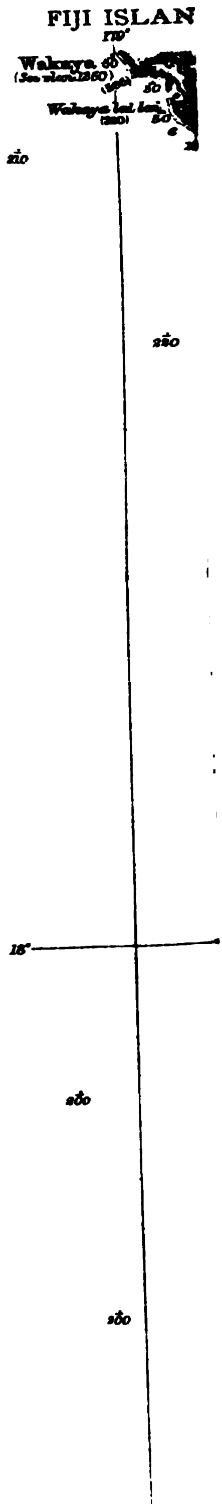

178°
5 MILES
19°
178°

FIJI ISLANDS AND C(


13.
Nai Salimu
18
S.
1150 ft
2.
Sea Level
20
17
5
N.W.
115
3.
Sea Lev
12
18
22
40
W.
4.
Sea
9
11
14
15
40
W.
Sharks Peak
830 ft.
6.
5
14
22
N.W.
8.
Sea Leve
16
20
22
W.
Wakaya



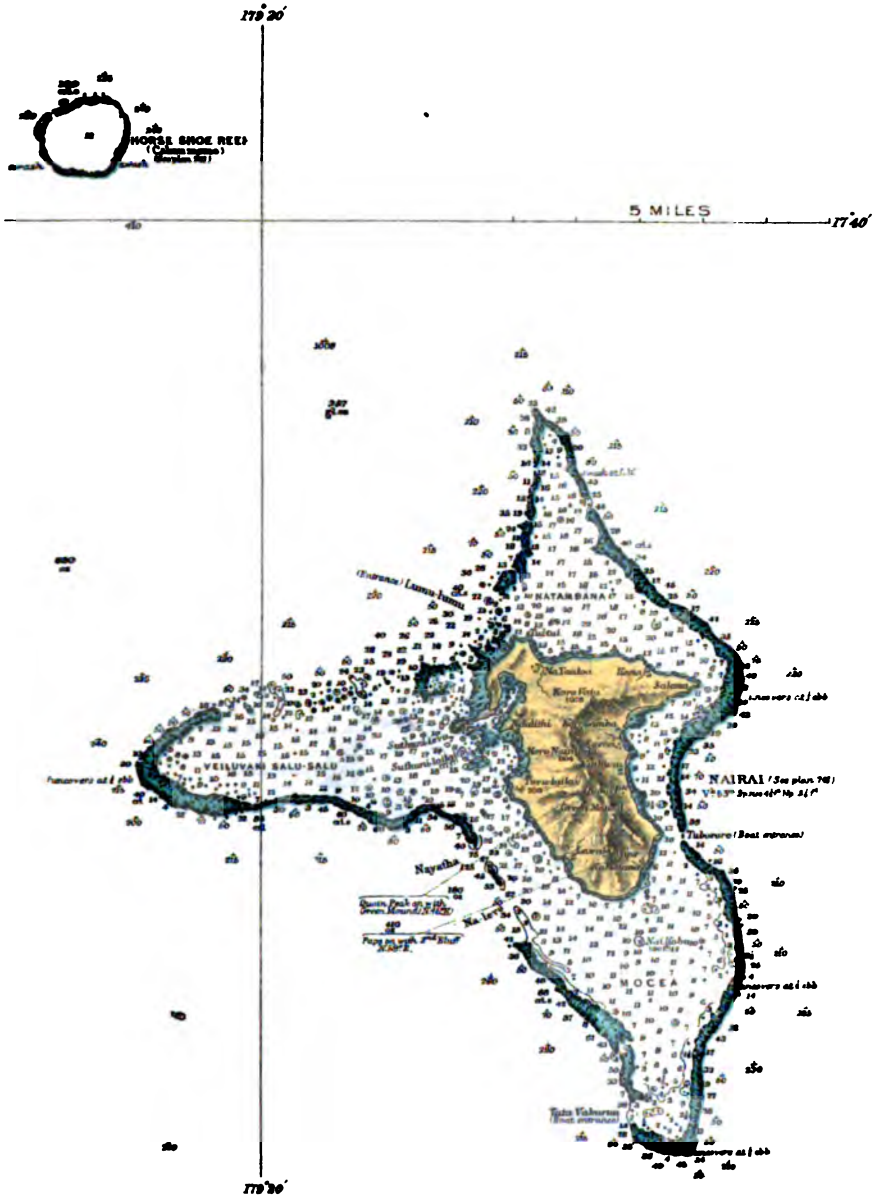
B Meisel lith Boston


FIJI ISLAN
Wakaya
Wakaya lai lai
210
250
18°
200
150
179°

Soundings in fathoms.

5 MILES

THE HELIOTYPE PRINTING CO., BOSTON

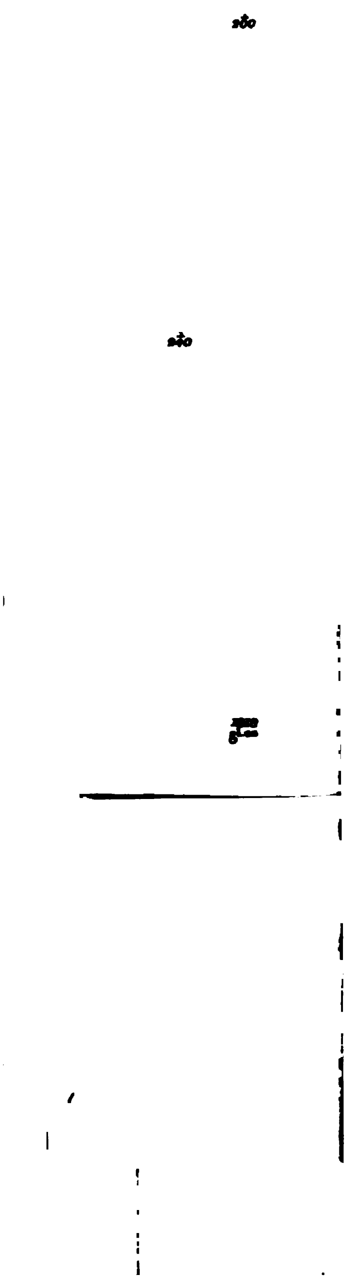


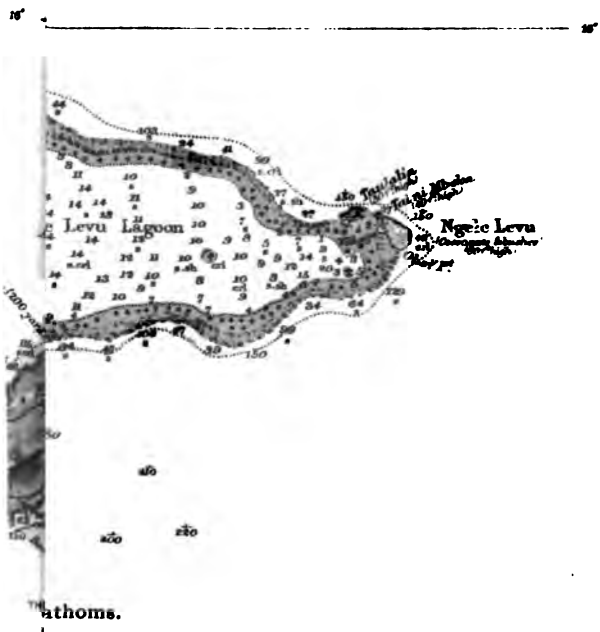
Soundings in fathoms.

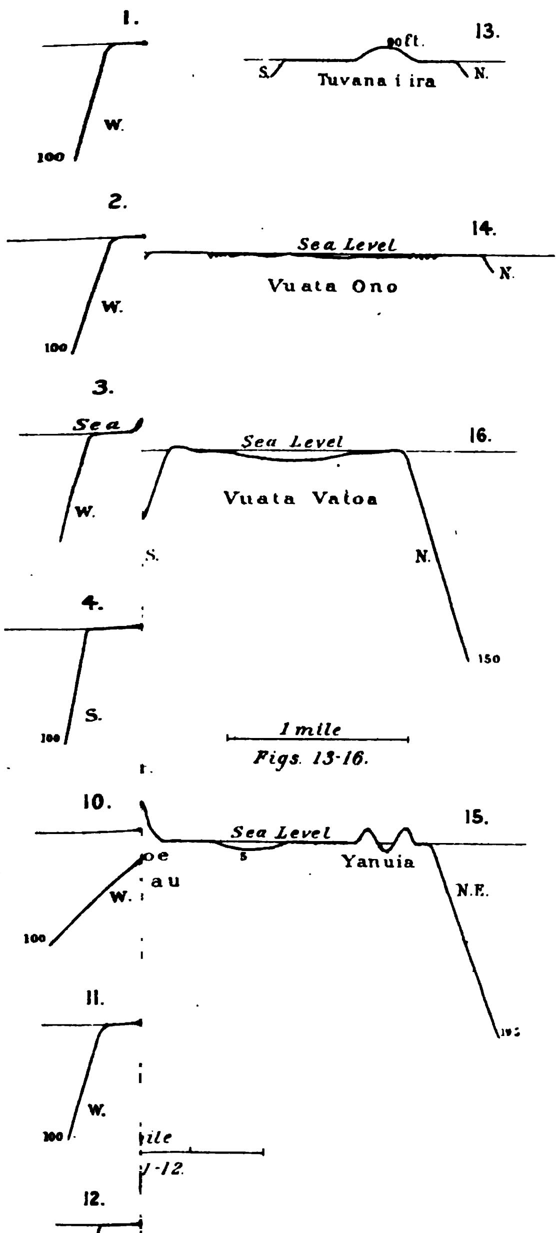
FIJI ISLANDS AND CORAL REEFS. PL. 15.

THE HELIOTYPE PRINTING CO., BOSTON

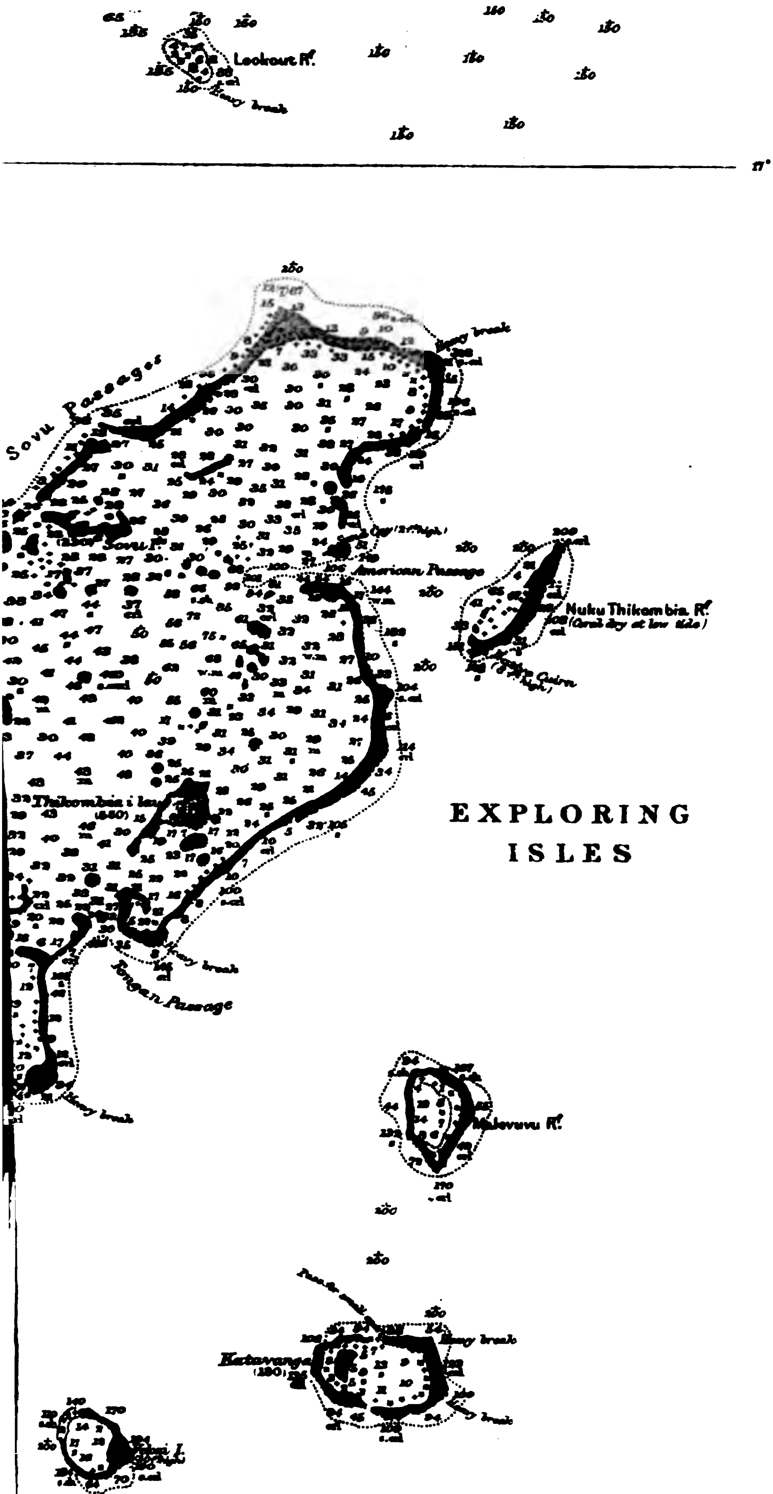
FIJI ISLAND



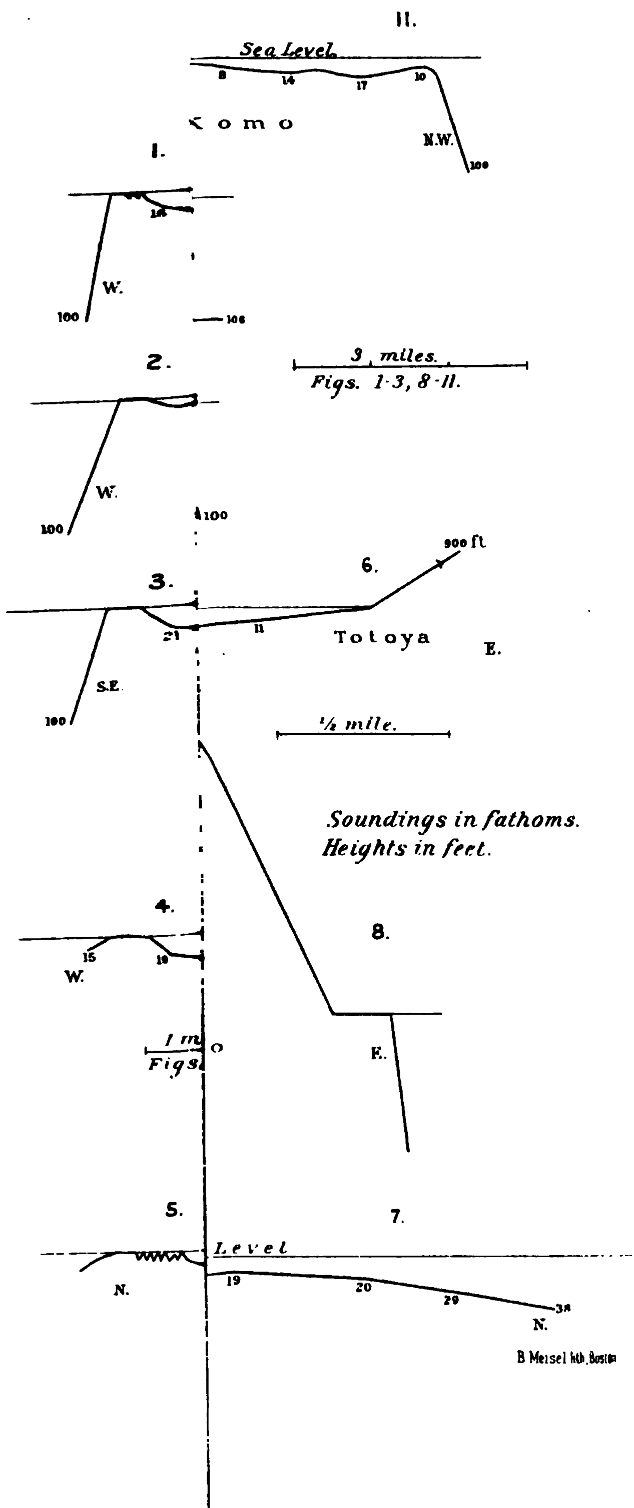

Levu Lagoon
Ngele Levu
Tavulali
athoms.



ndings in fathoms.
hts in feet.

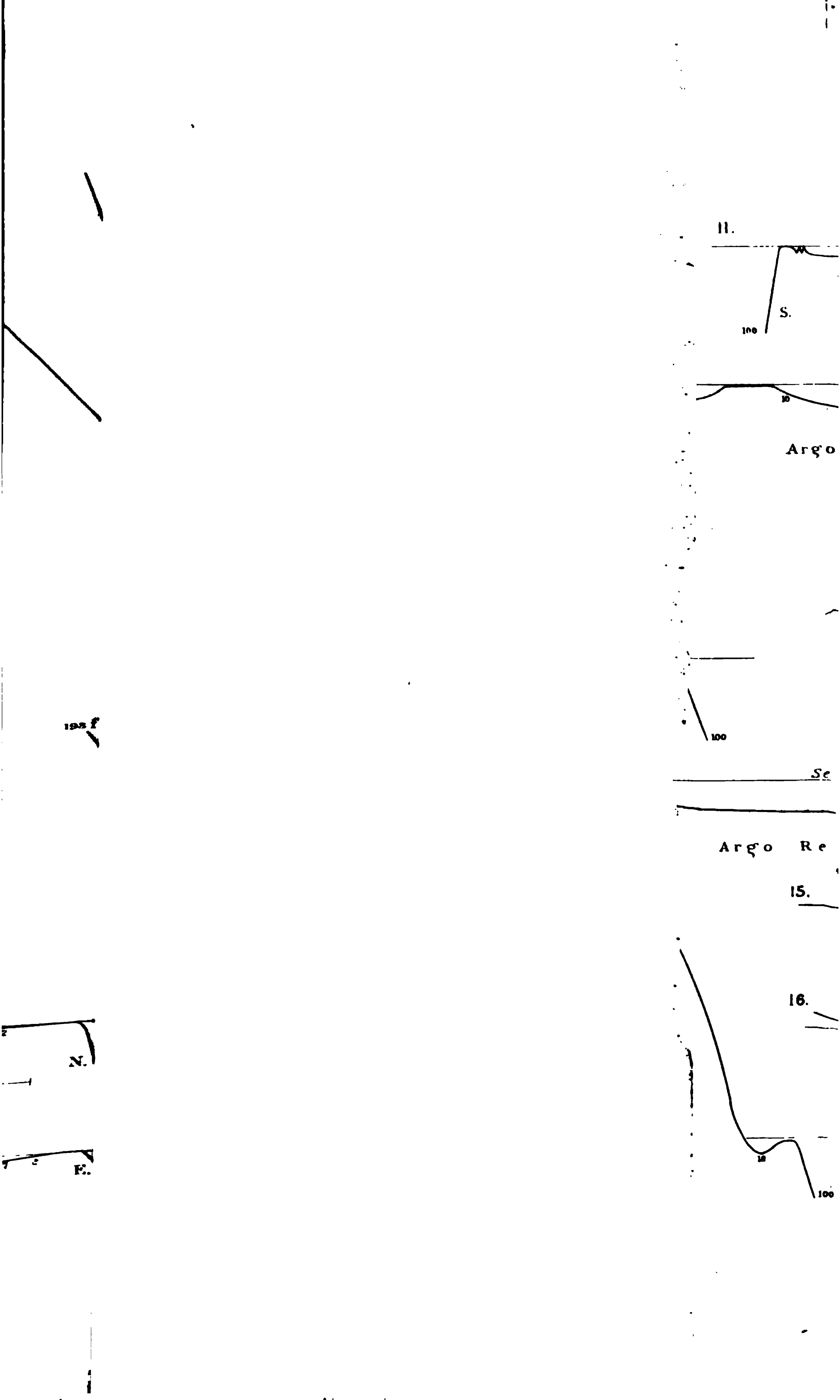

Lookout Rf.
Heavy break
17°
Sovu Passage
Sovu Pt.
American Passage
Nuku Thikombia Rf.
(Coral dry at low tide)
EXPLORING
ISLES
Thikombia island
Tongan Passage
Malevuvu Rf.
Katavanga
(180)

ns.

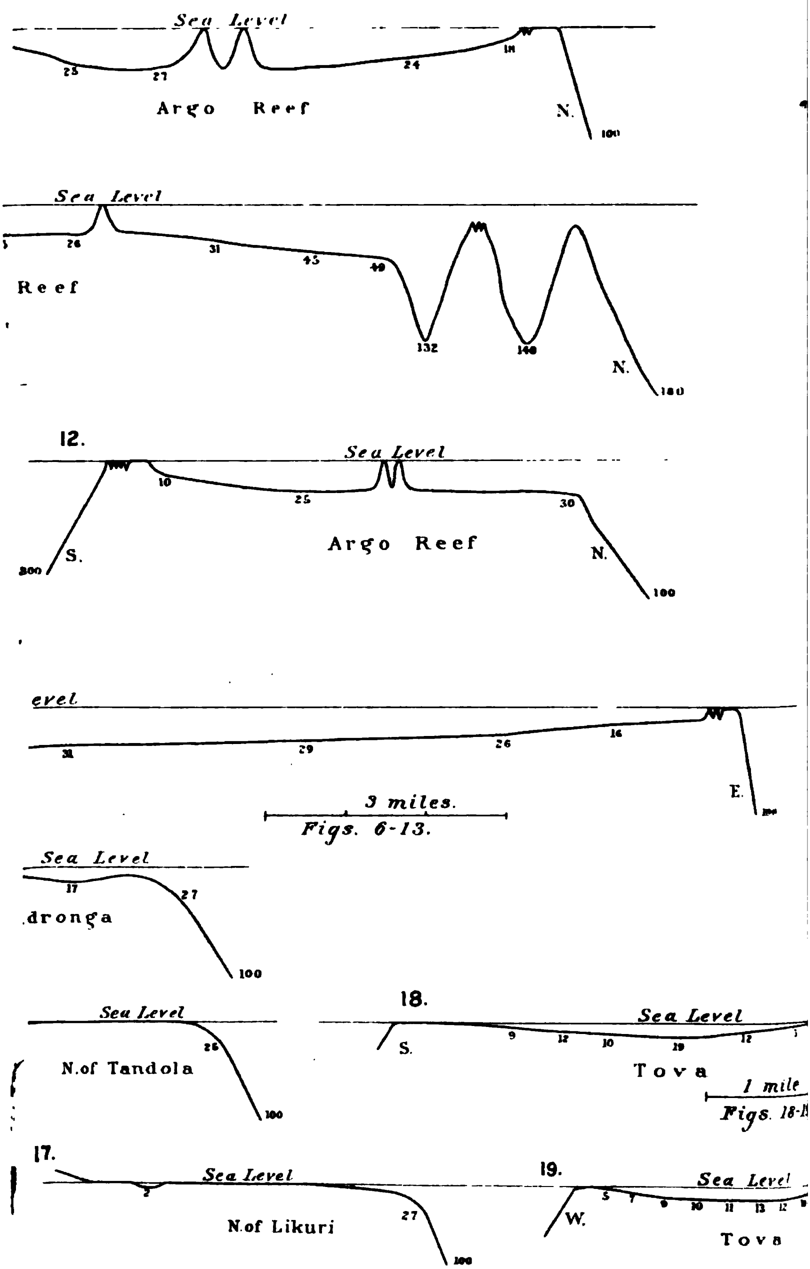


B Meisel lith. Boston

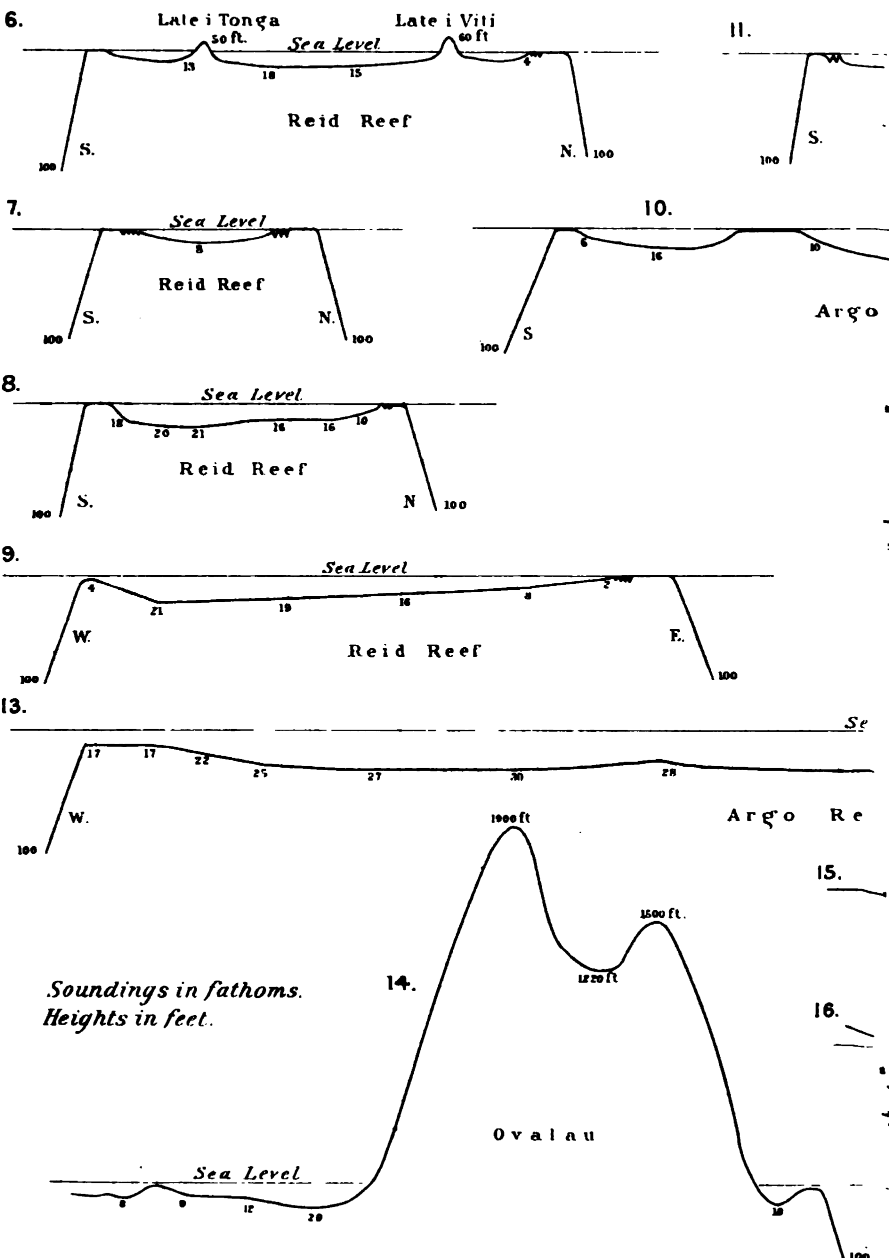

Thakau



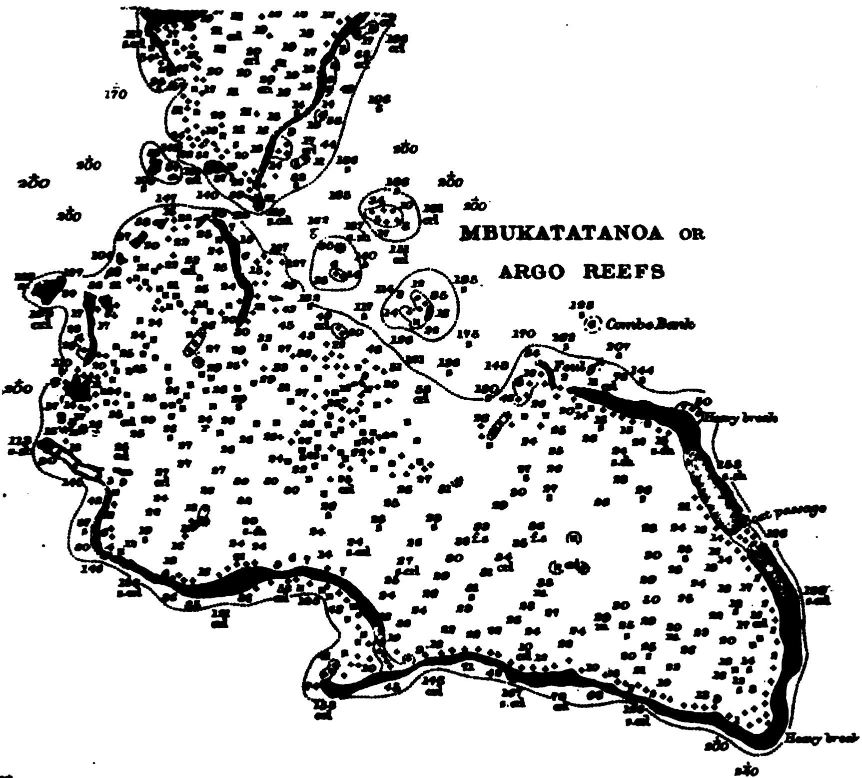
193 f
N.
E.
11.
S.
100
10
Argo
100
Se
Argo Re
15.
16.
10
100

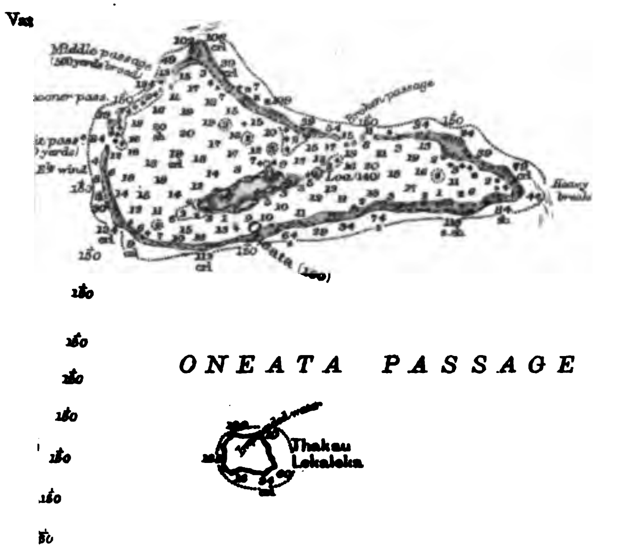


Sea Level
25
27
24
18
Argo Reef
N.
100
Sea Level
26
31
45
40
Reef
132
140
N.
180
12.
Sea Level
10
25
30
Argo Reef
S.
300
N.
100
evel
29
26
16
E.
3 miles.
Figs. 6-13.
Sea Level
17
27
dronga
100
Sea Level
26
N.of Tandola
100
18.
Sea Level
S.
9
12
10
19
12
Tova
1 mile
17.
Sea Level
2
N.of Likuri
27
100
19.
Sea Level
W.
5
7
9
10
11
13
12
Tova


6.
Late i Tonga
50 ft.
Late i Viti
60 ft
Sea Level
Reid Reef
S.
N.
100
11.
S.
7.
Sea Level
Reid Reef
S.
N.
10.
Argo
8.
Sea Level
Reid Reef
9.
Sea Level
Reid Reef
W.
E.
13.
W.
Argo Re
1900 ft
1500 ft.
1220 ft
14.
15.
16.
Soundings in fathoms.
Heights in feet.
Ovalau
Sea Level
2 miles.

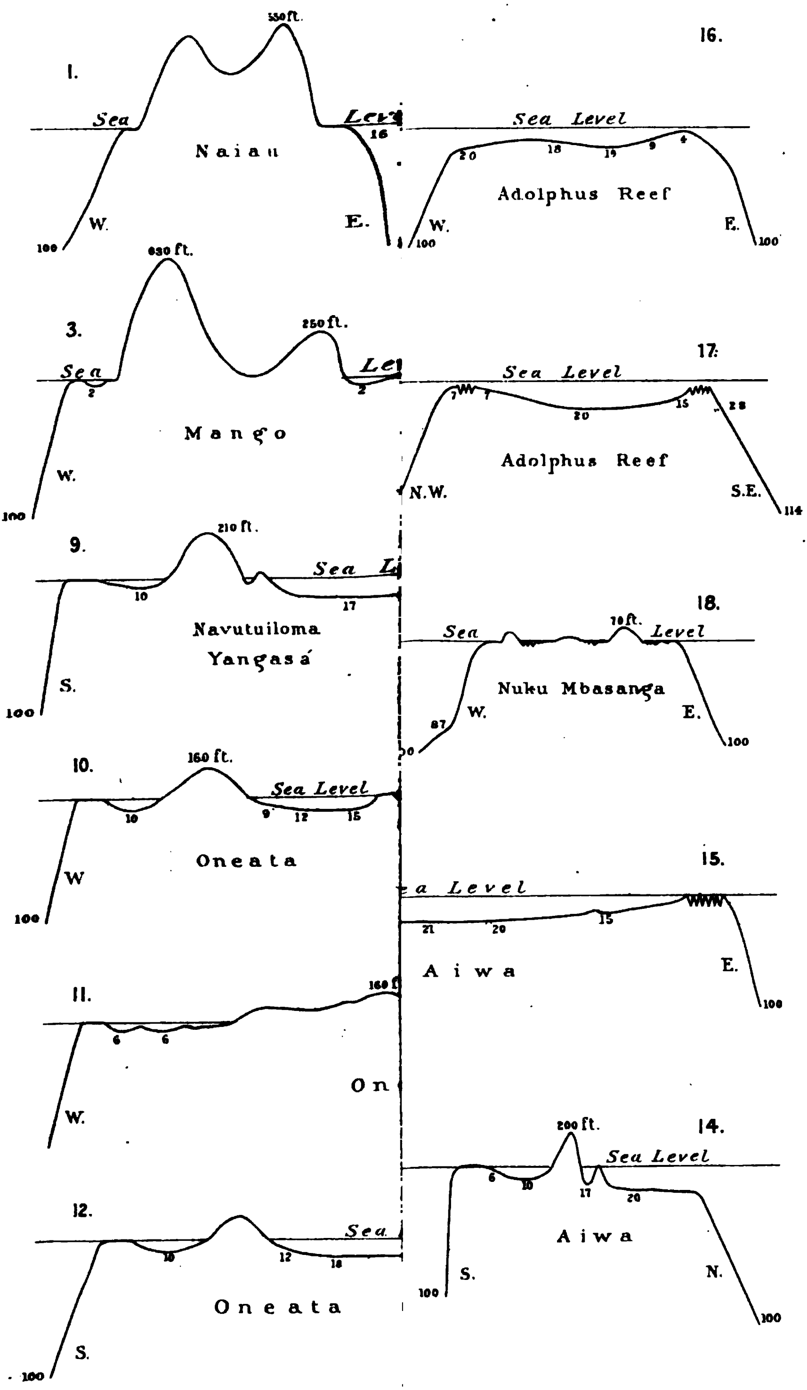
Figs. 14-17.


MBUKATATANOA OR
ARGO REEFS
Combe Bank
Heavy break
Heavy break


Middle passage
Broken passage
Loa
Heavy break
ONEATA PASSAGE
Thakau
Lekaleka

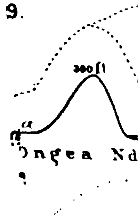
FIJI

FIJI



B. Meisel lith. Boston

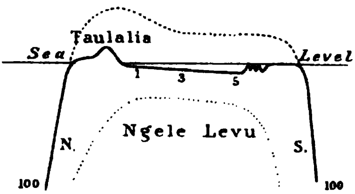
9.



10.

11.

8.



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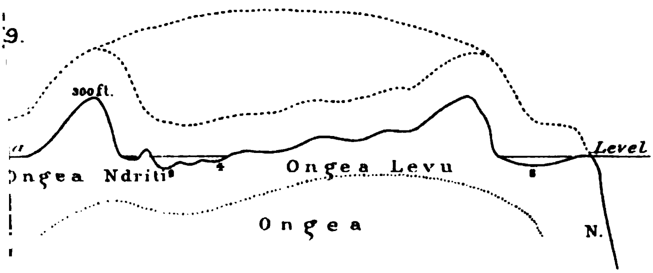

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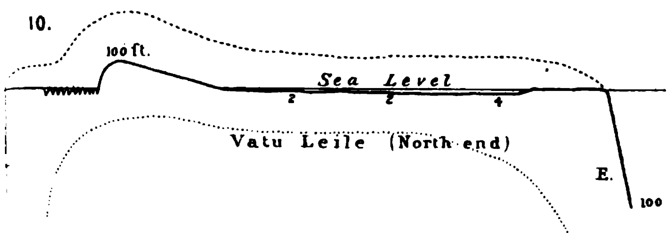

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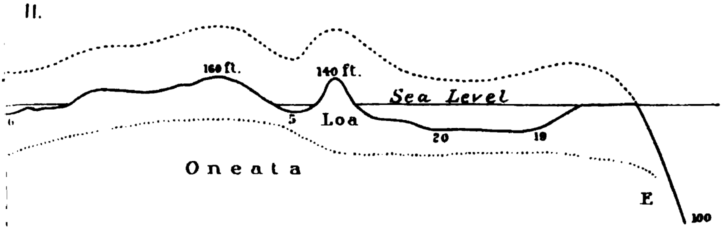
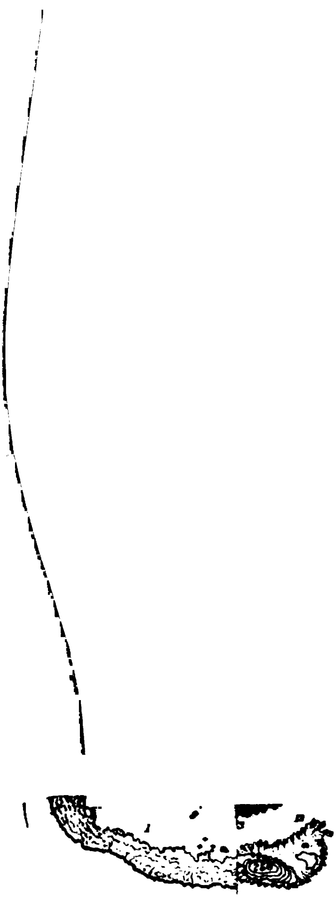
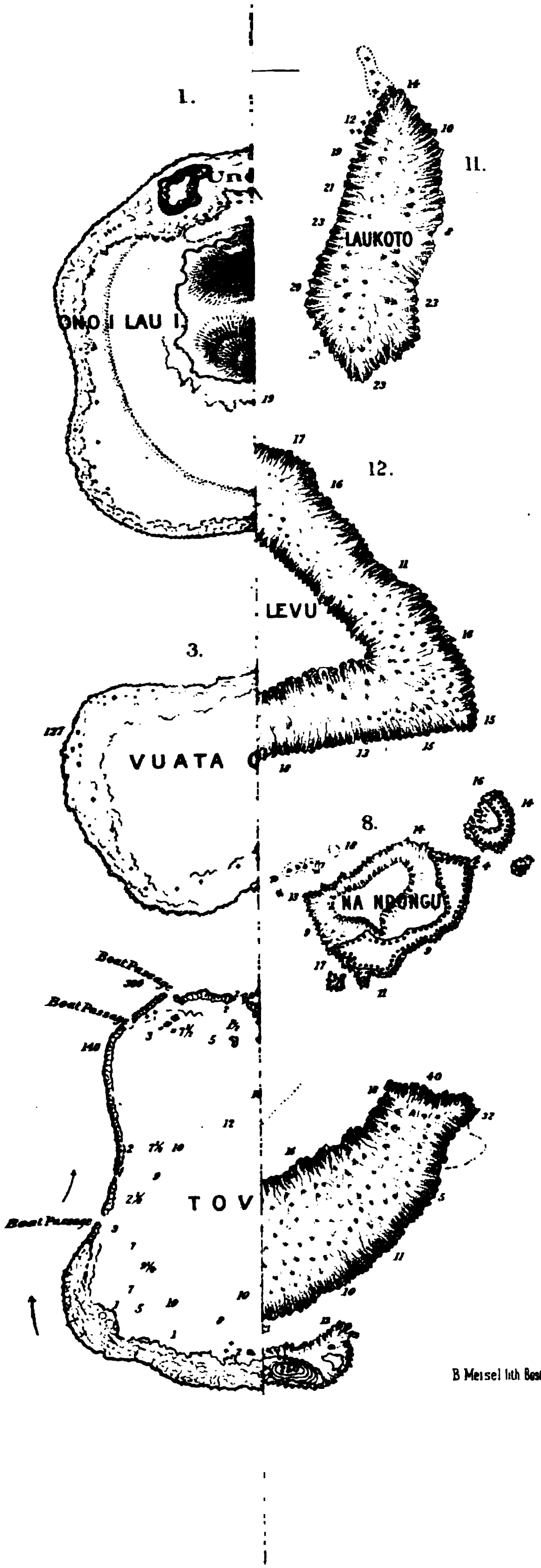


Soundings in fathoms.
Heights in feet.

B. Meisel lith. Boston.



B. Meisel lith. Boston.



B Meisel lith Boston.

M. A. PHOTO.

ARTOTYPE. E. BIERSTADT N. Y.

ENTRANCE TO SUVA HARBOUR THROUGH BARRIER REEF.

BARRIER REEF, ACROSS LAUTHALA BAY.

W. MOM. W. PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

REEF FLAT, WEST SIDE OF ENTRANCE TO SUVA.

W. MCM. W., PHOTO

ARTOTYPE, E. BIERSTADT, N. Y.

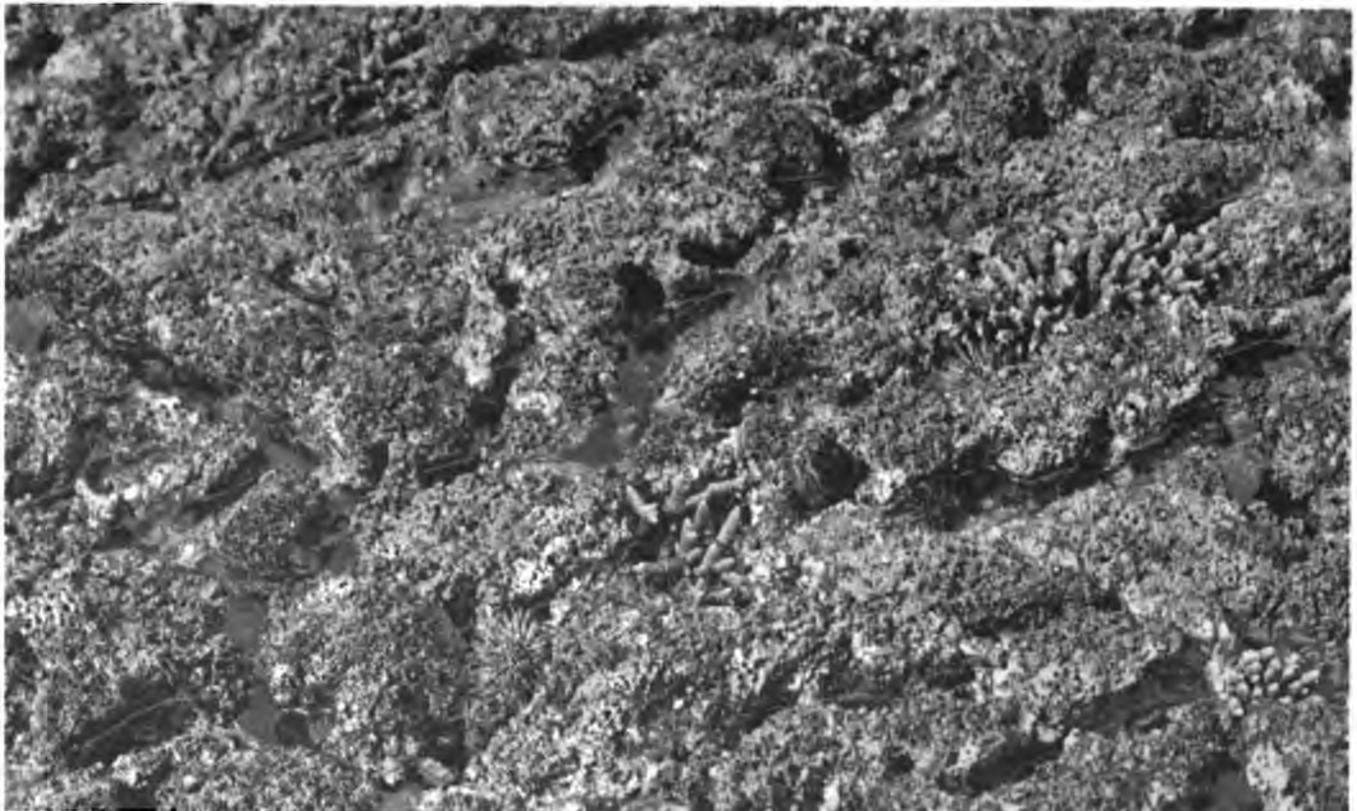
REEF FLAT, WEST SIDE OF ENTRANCE TO SUVA.

W. MCM. W., PHOTO ARTOTYPE. E. BIERSTADT, N. Y.

POCILLOPORA FLAT, EAST SIDE OF ENTRANCE TO SUVA.

W. MCM. W. PHOTO ARIOTYPE E. BIERSTADT, N.Y.

POCILLOPORA FLAT, EAST SIDE OF SUVA ENTRANCE.



WOODWORTH, PHOTO ARTOTYPE, E. BIERSTADT, N. Y.

CHANNELS DUG BY ECHINOMETRA.

M. A., PHOTO. ARTOTYPE. E. BIERSTADT, N. Y.

ELEVATED LIMESTONE BLUFF, NORTH OF SUVA.

MAX AGASSIZ, PHOTO.

THE HELIOTYPE PRINTING CO. BOSTON

ELEVATED LIMESTONE ISLET, INNER HARBOR OF SUVA.

WOODWORTH PHOTO.

ARTOTYPE, E. BIERSTADT, N.Y.

OVALAU FROM THE EAST.

WOODWORTH PHOTO　　ARTOTYPE, E. BIERSTADT, N. Y.

LEVUKA FROM THE EAST.

W. MCM. W. PHOTO. ARTOTYPE. E. BIERSTADT, N.Y.

FLATS LOOKING SOUTH WEST FROM MBAU.

MAX AGASSIZ, PHOTO.

THE HELIOTYPE PRINTING CO. BOSTON

VIWA ISLAND. MBAU WATERS.

W. McM W. PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

NASILAI REEF. SEEN FROM THE EAST.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

NUKULAU AND MOKALUVA ISLANDS.

PLATE 39.

MAX AGASSIZ, PHOTO.

THE HELIOTYPE PRINTING CO. BOSTON

NORTH SHORE OF NUKULAU ISLAND

MAX AGASSIZ, PHOTO.　　THE HELIOTYPE PRINTING CO. BOSTON

NUKULAU ISLAND FLAT.

MAX AGASSIZ, PHOTO.

THE HELIOTYPE PRINTING CO. BOSTON

NUKULAU ISLAND FLAT.

MAX AGASSIZ, PHOTO

THE HELIOTYPE PRINTING CO BOSTON

FRINGING REEF FLAT, OFF KORO LEVU.

A. A., PHOTO

ARTOTYPE. E. BIERSTADT, N. Y.

FRINGING REEF, SOUTH OF SINGATOKA RIVER.

M. A. PHOTO.

ARTOTYPE, E. BIERSTADT, N.Y.

SAND DUNES NORTH OF SINGATOKA RIVER.

MAX AGASSIZ, PHOTO

THE HELIOTYPE PRINTING CO. BOSTON

SOUTH POINT OF THUVA HARBOR.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

CLIFFS, EAST SIDE OF MBENGHA.

WOODWORTH PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

SHORE BLUFF RUKUA. MBENGHA.

M. A., PHOTO.

ARTOTYPE, E. BIERSTADT, N.Y.

MBENGHA SEEN FROM MOTURIKI BAY.

WOODWORTH, PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

WESTERN POINT OF STORM ISLAND.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

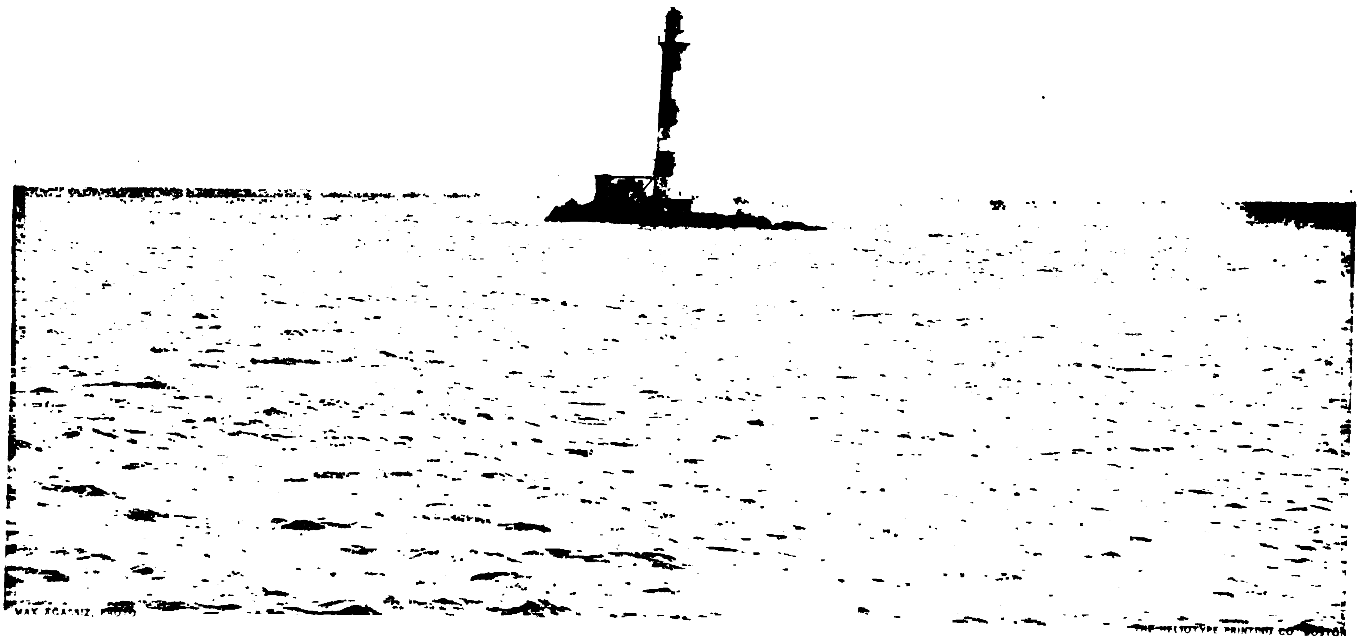
JOHN WESLEY BLUFFS, KANDAVU.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

NORTHWEST SIDE ONO ISLAND, GREAT ASTROLABE REEF LAGOON.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

YAUKUVE LAI LAI. GREAT ASTROLABE REEF LAGOON.



SOLO ROCK LIGHT-HOUSE, NORTH ASTROLABE REEF LAGOON.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

SOLO ROCK, NORTH ASTROLABE REEF LAGOON.

M A., PHOTO.

ARTOTYPE. E. BIERSTADT N. Y.

WEST FACE OF WAKAYA ISLAND.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

SOUTH SIDE OF PASSAGE INTO WAKAYA LAGOON.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y

EAST SIDE OF MOALA.

M. A., PHOTO.

ARTOTYPE. E. BIERSTADT N. Y.

SOUTH WEST SIDE OF NAIRAI.

WOODWORTH, PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

KOBU ISLAND, NAIRAI LAGOON.

ISLETS OFF NORTH POINT OF TAVIUNI.

WOODWORTH, PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

KIMBOMBO ISLANDS.

E. G. JONES, PHOTO.

ARTOTYPE, E. BIERSTADT N. Y.

ERODED SHORE, LAU.

MAX AGASSIZ, PHOTO

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NORTHEAST POINT OF KOMO.

WOODWORTH, PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y.

BEACH, NORTH SHORE OF KOMO.

WOODWORTH PHOTO

ARTOTYPE. E. BIERSTADT, N. Y

POCILLOPORA FLAT, KOMO.

M. A., PHOTO.

ARTOTYPE, E. BIERSTADT, N.Y.

EAST RIM OF TOTOYA, SEEN ACROSS THE ISTHMUS.

MAX AGASSIZ, PHOTO.

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OPENING INTO TOTOYA CRATER BASIN.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

LOOKING INTO CRATER OF TOTOYA FROM GULLET.

MAX AGASSIZ, PHOTO

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NORTHEAST RIM OF TOTOYA CRATER BASIN.

A. J. ODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

ERODED RIM OF CRATER BASIN OF THOMBIA.

ARTOTYPE, E. BIERSTADT, N. Y.

CRATER OF HALEAKALA

WOODWORTH PHOTO ARTOTYPE. E. BIERSTADT, N. Y.

NORTH EAST SIDE OF VANUA MBALAVU INSIDE OF LAGOON.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

NORTH EAST POINT OF NGILLANGILLAH ISLAND.

WOODWORTH PHOTO

ARTOTYPE, E. BIERSTADT, N. Y.

CAÑON, EAST SHORE OF NGILLANGILLAH ISLAND.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

AVEA ISLAND, VANUA MBALAVU LAGOON.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

ALCYONARIAN FLAT, NGILLANGILLAH ISLAND.

WOODWORTH, PHOTO ARTOTYPE, E. BIERSTADT, N. Y.

LIMESTONE BLUFF, NORTH OF TOKALAU BEACH, KAMBARA.

M. A., PHOTO.

ARTOTYPE. E. BIERSTADT N. Y.

VOLCANIC HILL, SOUTH OF TOKOLAU, KAMBARA.

MAX AGASSIZ, PHOTO.

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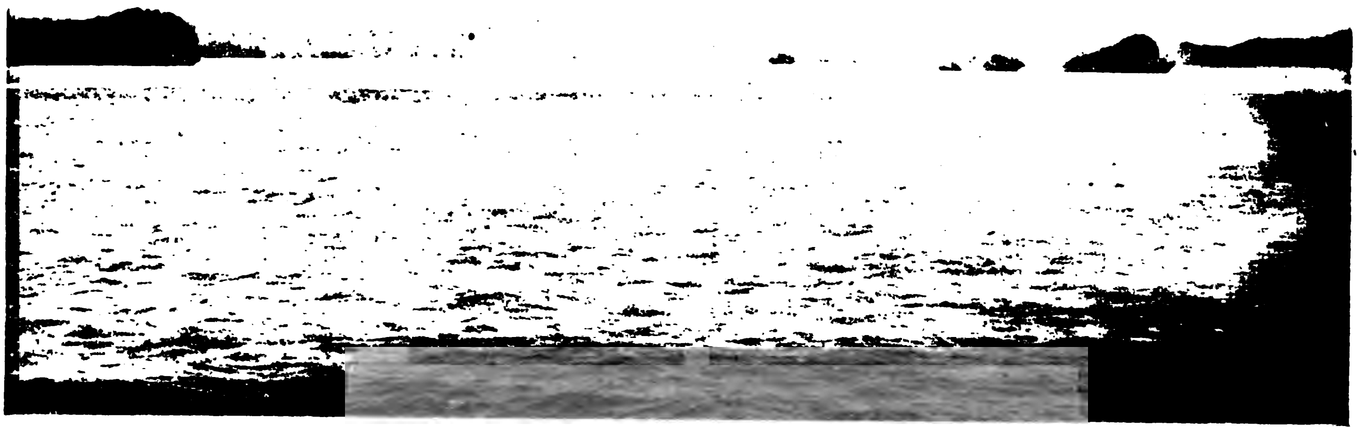
ELEVATED LIMESTONE CLIFFS. NORTHWEST SHORE OF KAMBARA.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

SOUTHEAST SIDE OF FULANGA.



MAX AGASSIZ, PHOTO

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LOOKING INTO FULANGA SOUND AND LAGOON FROM THE EAST.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

ENTRANCE INTO FULANGA LAGOON AND SOUND.

MRS. HATHAWAY, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

ISLETS IN FULANGA SOUND.

ARTOTYPE, E. BIERSTADT, N. Y.

ISLETS IN FULANGA SOUND.

WOODWORTH, PHOTO.

HELIOTYPE, E. BIERSTADT, N. Y.

LOW GAP, NORTH EAST COAST OF MANGO.

WOODWORTH PHOTO

ARTOTYPE. E. BIERSTADT, N. Y.

ELEVATED LIMESTONE BLUFFS, EAST COAST OF MANGO.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

VOLCANIC ISLETS ON SOUTH WEST SIDE OF MANGO

NORTHWEST POINT OF TUVUTHA.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

SOUTHEAST POINT OF TUVUTHA.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y

YAVUTHA FROM THE SOUTHEAST, INSIDE YANGASÁ LAGOON.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

BAY ON NORTH SIDE OF NAVUTUILOMA, YANGASÁ.

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POINT ON NORTH SHORE OF NAVUTUILOMA, YANGASÁ.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

ISLET IN BAY OF NAVUTUILOMA, YANGASÁ.

MAX AGASSIZ, PHOTO.

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NORTH SHORE OF ONGEA NDRIKI.

MAX AGASSIZ, PHOTO THE HELIOTYPE PRINTING CO. BOSTON

TAULALIA ISLET, NGELE LEVU LAGOON.

MAX AGASSIZ, PHOTO

THE HELIOTYPE PRINTING CO. BOSTON

NORTHERN POINT OF TAINI MBEKA ISLAND, NGELE LEVU LAGOON.

WOODWORTH PHOTO ARTOTYPE. E. BIERSTADT, N. Y.

CENTRAL PART OF NGELE LEVU.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO. BOSTON

HONEYCOMBED SURFACE OF NGELE LEVU ISLAND.

WOODWORTH, PHOTO. ARTOTYPE E. BIERSTADT, N. Y.

VEGETATION, WEST SHORE OF NGELE LEVU.

M. A., PHOTO. ARTOTYPE, E. BIERSTADT N. Y.

BLUFF, NORTH WEST SHORE OF VATU LEILE

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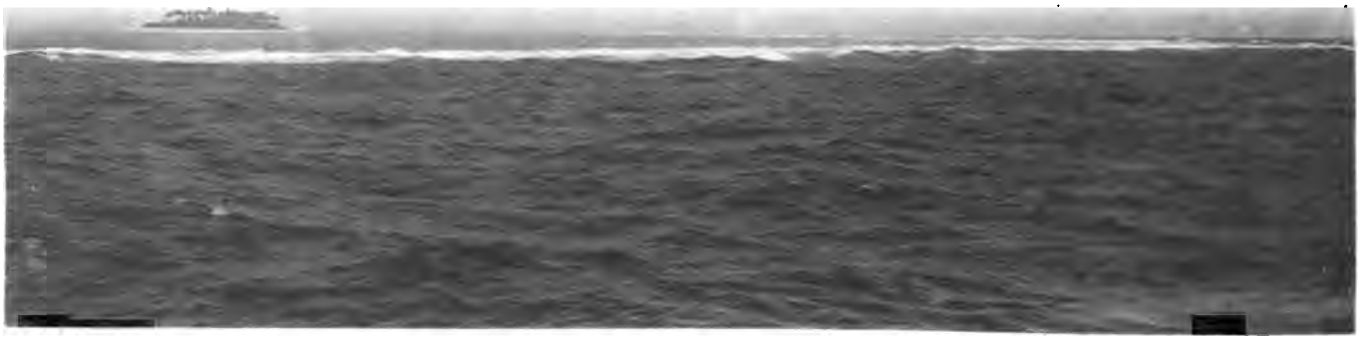
VATU SAVU ISLETS, VATU LEILE LAGOON.

WOODWORTH, PHOTO.

ARTOTYPE, E. BIERSTADT, N. Y

VATU LAILAI ISLETS, VATU LEILE.



WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

SOUTHERN HORN OF NANUKU LEVU.

MAX AGASSIZ, PHOTO THE HELIOTYPE PRINTING CO. BOSTON

NANUKU LEVU, SEEN FROM THE WEST.

M. A., PHOTO

ARTOTYPE E. BIERSTADT, N. Y.

SOUTHERN REEF FLAT OF NANUKU LEVU.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

ON EAST SHORE OF NANUKU LEVU.

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NEGRO HEADS, OCCUPYING POSITION OF NANUKU LAI LAI ISLAND.

W. MCM. W. PHOTO.

ARTOTYPE. E. BIERSTADT, N.Y.

NUKU MBALATE AND NUKU MBASANGA.

MAX AGASSIZ, PHOTO.

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WESTERN POINT OF WEILANGILALA.

WOODWORTH, PHOTO. ARTOTYPE, E. BIERSTADT, N. Y.

NORTHEAST POINT OF WEILANGILALA ISLAND.

WOODWORTH PHOTO ARTOTYPE. E. BIERSTADT, N. Y.

SOUTH EAST HORN OF THAKAU LEKALEKA.

MAX AGASSIZ, PHOTO. THE HELIOTYPE PRINTING CO BOSTON

NORTHEAST HORN OF MOTUA LAI LAI.